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A COMPUTER ANALYSIS OF ERTS DATA OF THE LAKE GREGORY AREA OF SOUTH AUSTRALIA WITH PARTICULAR EMPHASIS ON ITS ROLE IN TERRAIN CLASSIFICATION FOR ENGINEERING

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by

G.D. LODWICK

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(E83-10178) A COMPUTER ANALYSIS OF ERTS DATA OF THE LAKE GREGORY AREA OF SOUTH AUSTRALIA WITH PARTICULAR EMPHASIS ON ITS ROLE IN TERRAIN CLASSIFICATION FOR ENGINEERING M.S. Thesis (New South Wales

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DECLARATION

The research work for this thesis was carried out in the School of Applied Geology, University of New South Wales. Where the work of others, whether published, unpublished or personally communicated has been referred to or made use of, full acknowledgement has been given.

In addition to the thesis, a number of research and technical papers have been submitted, none of which has previously been presented in whole or in part to any university or institution for the purpose of gaining a higher degree. The work for these was carried out at the Bureau of Mineral Resources, Canberra, C.S.I.R.O. Division of Soil Mechanics, Melbourne, and Monash University, Melbourne. Where these papers involve more than a single author, each author has made a significant contribution, both to the theoretical development of the topic and to its practical implementation.

G. D. Lodwick

G.D. Lodwick

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ABSTRACT

This research project was undertaken to carry out an analysis of Earth Resources Technology Satellite (ERTS) multispectral data and examine its usefulness as a means for allowing automatic terrain classification for engineering purposes. The approach used involved mathematical manipulation of the original data in order to highlight the relationships between the original video elements. The specific locality investigated was a strip approximately 185 km long and 46.25 km wide centred on Lake Gregory in the north-east of South Australia. All of this area falls into the arid zone, and such terrain is of considerable extent in Australia and throughout the world. 'Ground truth' had previously been established by means of conventional techniques (aerial photographs and ground investigations) and the results displayed by terrain pattern maps at a scale of 1:250000 (Grant, 1970 a,b,c). The study was thus directed at a regional rather than a detailed level and was concerned with correlating and classifying the smallest identifiable elements of terrain at such a scale represented by approximately one-eighth inch squares on the terrain pattern map.

As the ERTS video data elements each cover a ground size of approximately 79 x 79 metres, consolidation into macro-elements comprising on average 10 x 11 each (around half mile squares of terrain) was carried out. These macro-elements were used as the basic elements in the analyses. The data was stored on a magnetic tape file and a number of computer programs were written to carry out the analysis and to display the results pictorially.

Display of the original band data indicated differences in representation of the terrain both within and between each of the four

bands. By applying principal components analysis to the variance/covariance data matrix, scores of the video elements on the principal component axes allowed good correlation to the various provinces of Grant (1970 a,b,c). Within the provinces there was a high level of qualitative differentiation which could be related to the terrain patterns established by conventional means. A cluster analysis of the data also enabled correlation at the terrain pattern level with the resulting dendrogram highlighting quantitatively the interrelationships between the various terrain elements.

These results show that meaningful evaluation and classification of terrain for engineering can result from a quantitative analysis of ERTS data. However this approach has two important advantages over conventional methods. First because of its use of modern computer techniques, large areas (of size 185 x 185 km) can be classified into fundamental units in a matter of hours, and secondly it can be applied to those parts of the earth where facilities for conventional studies (e.g. aerial photographs, roads) are poor or lacking. In this way the application of such techniques can contribute significantly at the regional level to the understanding of terrain in remote or underdeveloped regions and to the classification of terrain for engineering purposes.

CHAPTER 1: INTRODUCTION

1.1 Terrain Classification for Engineering

In 1966 and 1967 the author was employed at the C.S.I.R.O. Division of Soil Mechanics, Melbourne, Victoria. During this period he was associated with an on-going program to develop a system of terrain evaluation for engineering purposes. Methods were developed to classify terrain in the laboratory by means of air photos, using stereoscopic pairs, and for these classifications to be confirmed in the field by inspection and soil testing. The methods involved the use of the human eye as the recording instrument to carry out a qualitative correlation of individual sites with others at a distance by observation and interpretation of geology, geomorphology, physiography and stream and vegetation patterns.

The underlying philosophy of the system is that having established a mozaic of visually correlated features then by carrying out site investigations in the field and measuring appropriate properties of a relatively small number of selected sites, a broad knowledge of the engineering properties of a regional area can be determined. Considerable experience has shown this approach to be effective in terms of the classification of terrain into meaningful subdivisions in an engineering sense (Aitchison and Grant, 1967; 1968 a,b).

Over recent years a number of practical terrain surveys have been carried out using these methods in association with projects such as outback road construction, for purposes of establishing mobility in remote areas, and for classification and evaluation as a basis for urban and rural planning. In 1967 the author was involved in two such surveys (one to the Gulf of Carpentaria and one to the north-east of Marree in

South Australia) during periods when road construction and alignment were being undertaken.

In conjunction with such field work, a data base computer system was developed to utilize the speed and storage facilities of the computer to assist in overcoming problems associated with the storage and retrieval of vast amounts of field and laboratory data (Grant and Lodwick, 1968). While such a system was of considerable importance, of more fundamental interest was the possibility of making use of the computer for mathematical analysis of video data in order to assist in the establishment of the basic classifications.

Until recently, however, it was not practicable to carry out such an analysis since it would involve as a prerequisite the determination of numeric values for all visual data sites throughout a full survey area. In addition the allocation of a single visual value to each site would be unlikely to result in meaningful classes of terrain, since visual assessment also depends upon the interrelationships of individual sites (such as their roles in trends). What was necessary was the sensing and measurement of a number of attributes peculiar to the site itself, or alternatively the inclusion of information representative of surrounding sites such as directional information on trend features.

By a multivariate analysis of all these attributes the aim would be to determine a unique 'signature' for each particular site, which could then be compared with 'signatures' of other sites. In this way naturally occurring similarities or differences could be highlighted and used as a basis for classification.

1.2 Collection of ERTS Data

The ERTS (Earth Resources Technology Satellite) program collects as one of its priorities multispectral data of images of the earth's surface. These data are collected remotely from a satellite orbiting the earth by means of a sensing system, transmitted to a receiving station and then translated and assembled onto computer tapes suitable for digital processing.

Reflected solar light is measured in four visible spectral bands in the range between 0.5 and 1.1 micrometers.

The system scans a 185 km swathe from west to east as the satellite traverses an almost polar orbit. Each swathe comprises six lines sensed by sets of six parallel detectors. Each line is made up of 3240 individual readings and 2340 lines comprise an individual scene covering 185 x 185 km of the earth's surface.

The usefulness of ERTS data in the field of terrain studies is enhanced by the enormous coverage of each scene, the multispectral nature of the observations, and the fact that the data are collected as numeric values which are amenable to multivariate analyses using modern computer techniques.

1.3 Selection of the Lake Gregory Area

The area selected for study is strip 1 of ERTS1 scene number 1564.23594 which comprises a section 46.25 km wide and 185 km long trending approximately fourteen degrees in a north-easterly direction. It is centred on Lake Gregory, a complex of claypans and swamps approximately 120 km to the north-east of Marree in the north of South Australia (Figure 1.1). It lies within the southern margin of the Great Artesian Basin and fringes the Simpson Desert which is situated to the north.

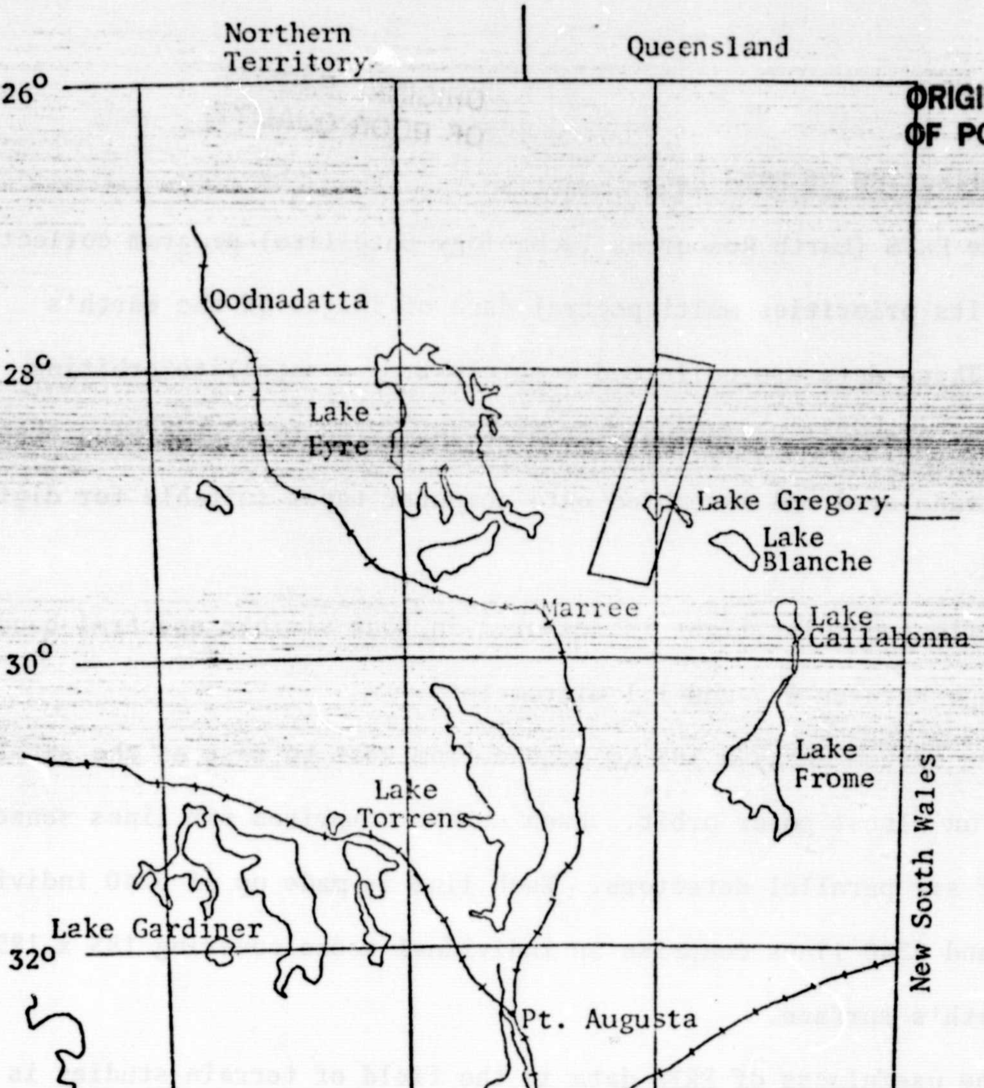

Figure 1.1: Locality Map of Lake Gregory Area.

The northern half of the strip consists of aeolian sand dunes of quaternary age trending northerly and northwesterly, while the southern part consists of Cretaceous and Tertiary deposits. Transecting from the north-east are the braided channels of Cooper's Creek running down to Lake Eyre.

ERTS data had been collected over this area in February 1974, and a terrain classification for engineering carried out in 1967. Very little of the area is covered by vegetation, and this allows the video information to be directly related to the terrain surface. In addition the whole of the locality is within the arid zone which is important because as Mitchell (1973) points out, such land shows a wide range of geological and physiographic conditions whose character and distribution have been much less studied than those of more settled regions. Because the world's total desert area is very large, the development of successful methods of terrain classification would have wide application for such purposes as the estimation of soil and water resources, the design of cross-country vehicles, and calculation of requirements of local materials for large-scale engineering projects.

1.4 Previous Work

1.4.1 Applications of ERTS data

The first Earth Resources Technology Satellite (ERTS1) was launched on July 23, 1972. In its first seven months over 34,000 scenes of the earth were obtained, covering all major land masses, and over 70 per cent of the world's land area.

Since its launch a wide range of investigations using ERTS data have been reported. These include geologic analyses (Lowman, 1972; Pickering and Jones, 1973), mapping of ice and snow conditions (McClain,

1972; Campbell, 1972), crop classification (Sheffield and Bernstein, 1972), ecological investigations (Anderson, Carter, McGinness, 1972; Wezernak and Thompson, 1972), flood mapping (Deutsch et al., 1973) and land use classification (Anderson et al., 1972). The most significant and successful application of ERTS data to date has been using ERTS photo images, especially as a photomozaic medium.

In Australia staff at the C.S.I.R.O. Division of Mineral Physics have developed techniques which take the original digitized computer compatible tapes and produce high quality photo images for use by researchers (Green, 1975). At the C.S.I.R.O. Division of Land Use Research work is being carried out using ERTS imagery for ecological surveys (Cook, 1975). At the South Australian Institute of Technology research is being carried out into detailed classification of ERTS data to investigate the use of such imagery for land use surveying (McCloy, 1975). Similar problems are being investigated at the CSIRO Division of Land Resources Management in Western Australia (Honey, 1976).

The Bureau of Mineral Resources has carried out investigation of ERTS for geological applications (Maffi et al., 1974; Tingey, 1974) while research in this area has also been carried out by the Department of Geology at the University of Melbourne, but with particular reference to geomorphological aspects (Joyce, 1974).

1.4.2 Terrain classification surveys

A considerable amount of work has been done in Australia in the development of terrain classification and evaluation systems (Christian, 1958; Mabbutt, 1968b; Christian and Stewart, 1964). Investigations in Australia have generally been integrated using a multidiscipline approach to landscape analysis, by including specialists in geology, pedology,

geomorphology, botany and climatology.

The C.S.I.R.O. Division of Land Use Research has carried out a number of important surveys (Christian and Stewart, 1953; Perry et al., 1962). These investigations have usually considered the whole range of land use interests(including the engineering aspects, water supply, minerals, wildlife, fisheries, harbours, scenery, tourist and recreational attractions) and encompass all those natural resource factors which have a relatively fixed geographical location and extent and are amenable to geographical forms of analysis (Christian and Stewart, 1964).

Since 1946 extensive resource surveys have been carried out in undeveloped parts of Australia and Papua New Guinea, using the aerial photography and techniques developed during World War II. These surveys were based on *land systems* and *land units* which aimed at being both basic and functional divisions of landscape. Land systems were recurrent patterns of landforms, soils and vegetation recognisable on aerial photographs and these comprised the basic mapping unit. Land units were their constituent subdivisions. Land system surveys were presented in the form of maps at scales of 1:250000 and 1:1M accompanied by block diagrams showing the interrelations of the land units and tabulated summaries of their form, soil, and vegetation properties. The results of these surveys have been applied to a wide range of land-use purposes, most notable of which is to the pastoral industry (Slatyer and Perry, 1969).

From such a broad scale approach, the C.S.I.R.O. Division of Soil Mechanics developed a system of terrain classification and evaluation for the particular needs of engineering. This is known as the Pattern Unit Component Evaluation (P.U.C.E.) system which has been applied in a number of surveys in Australia undertaken on a regional basis (Grant, 1970 a,b,c; 1972).

1.5 Methods of Investigation

The aim of this research was to investigate the extent to which a quantitative analysis of ERTS multispectral data could enable meaningful classification of terrain for engineering.

A survey of current literature suggested that the application of multivariate techniques of factor analysis and cluster analysis, such as outlined in standard texts (Davis, 1973; Harbaugh and Merriam, 1968; Miller and Kahn, 1962), would provide a new approach to the problem of classification of terrain data for engineering purposes.

Because the terrain classification maps of the Lake Gregory area to be used as 'ground truth' (Grant, 1970 a,b,c) were presented at a scale of 1:250000 the investigation concerned classification on a regional basis and involved detailed correlation to the level of terrain patterns.

A number of special purpose computer programs to store the data, to analyse and process video information, and to present the results pictorially were written for the research.

CHAPTER 2: TERRAIN CLASSIFICATION FOR ENGINEERING

2.1 Introduction

Terrain classification has practical application for agricultural, engineering, military and other purposes. It is usually concerned with intermediate levels of land use intensity where the interest in terrain per unit area is important, but not sufficient to justify the cost of special detailed surveys, e.g. it has been successfully applied in agriculture when choosing suitable farming systems, in engineering for purposes of secondary road construction in remote areas, and for military applications at the broad level of vehicle mobility.

Terrain evaluation can be defined as a process involving an analysis of the natural geographic environment, the classification of data to distinguish one area from another, and the appraisal or assessment of the data for practical ends (Mitchell, 1973). In practice the problems of classification of terrain fall into three main categories dealing with the complexity, extent and association of landscape forms. Additional to these a fourth aspect of scale might be added (Mabbutt, 1968 b).

The processes involved in land analyses and terrain studies normally comprise field surveys, laboratory work, statistical analyses, the extraction of classification details, and the storage of data in retrieval and reproduction systems so as to make it available to users in an accurate and comprehensible manner.

The role of classification in this process is to develop methods concerning the recognizability and reproducibility of the terrain so that individual properties can be precisely defined in terms of earth forms and materials. This is necessary so that prediction between known and unknown areas can be effectively carried out.

Terrain classification systems can adopt one of two approaches which should be considered complementary rather than conflicting (Mabbutt, 1968 b).

First, one can consider the terrain itself, classify it into natural units, and then attempt to measure individual properties quantitatively and relate them to land use.

Alternatively one can consider terrain from the point of view of the uses envisaged and map units in terms of selected class limits of appropriate land attributes. Superimposition of these maps will then give a complete classification.

The first or 'landscape' system has three significant advantages over the second or 'parametric' approach. It assists in explanation of the fundamental causes of landscape differentiation, it is better suited to reconnaisance, and it facilitates the appreciations of regions as a whole.

On the other hand the parametric approach is more quantitative and less dependent upon subjective interpretation of landforms. It is also better adapted to statistical analysis and the use of remote sensing methods. However it poses the difficulty of selection of meaningful class limits and tends to sacrifice comprehensiveness and ease of recognition for quantitative detail (Mitchell, 1973).

2.2 The Pattern Unit Component Evaluation System

Because of the special needs of engineering, and the inadequacy of conventional land systems, the C.S.I.R.O. Division of Soil Mechanics has devised a modified system for its own needs. This has land systems more narrowly defined in terms of engineering criteria but identified on the grounds of visual 'landscape' recognition characteristics.

The basis of the Pattern Unit Component Evaluation (P.U.C.E.) Programme is that any area of land can be uniquely defined in terms of its basic attributes, i.e. topography, underlying lithology, structure, and its soil and vegetation. By selecting class boundaries at suitable significant levels, continuous expanses of terrain may be reduced to a number of terrain classes which reflect its engineering properties.

The system is based entirely on landscape properties normally recognizable by engineers at four levels of scale: province, terrain pattern, terrain unit and terrain component, in descending order of size and increasing order of detail. Only the last three are considered as vehicles for engineering data. The method of relating such data to these is described by Aitchison and Grant (1967; 1968 a,b).

The smallest unit is the terrain component, which has a constant rate of change of slope, consistent soil at primary profile level, and consistent vegetation associations. It has a constant underlying lithology in a constant structural environment. It also has a consistent association of soils (except alluvial or aeolian stratified soils), such that the association can be expressed within one class in the Unified Soil Classification (USC, Anon 1963) System and within one class of the primary profile form (Northcote, 1971). It is mapped at a scale of 1:5000 or greater, and interpreted on aerial photographs at a scale of 1:10000 or greater. It can be mapped in situ and defined in terms of physiography, rock, soil, and vegetation, and of its relative importance within the terrain unit.

The key subdivision is the terrain unit which has to be visually recognisable and is defined as 'the area covered by a single landform feature having a characteristic soil association and a characteristic natural vegetative formation' (Grant, 1975). It is mapped at a scale of

1:50000 and described qualitatively in terms of principal soil, rock, and vegetation characteristics, and quantitatively in terms of lateral dimensions and relief using either aerial photographic interpretation or ground methods.

The terrain unit so defined can be regarded as being composed of a limited number of terrain components always recurring in the same spatial relationships within the terrain unit. The slopes and soil/ vegetation characteristics are those of the individually contributing terrain components. In practice the terrain unit falls into topographic classes (Table 2.1) and within each class has a characteristic association of slopes and a consistent local relief. In addition the characteristic soil association of the terrain unit will be dominated by a specific textural type (Table 2.2) and the characteristic vegetation formation will be dominated by a single vegetation class (Table 2.3).

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1. Surfaces, flat or with various degrees of undulation, i.e. undissected, dissected and/or eroded.
2. Slopes between surfaces; gentle, steep, or escarpment-like.
3. Isolated hills, ridges, etc. (except those with flat tops).
4. Drainage lines, lakes, etc.

Table 2.1: Examples of topographic terrain unit classes (from Grant, 1974)

1. Rock outcrop, pockets of shallow soil or gravel
2. Clay soils (Ug)*
3. Clay soils (U or G)
4. Clay soils (D)
5. Silty soils
6. Sand over clay soils (G)
7. Sand over clay soils (D)
8. Sandy soils (U or G)
9. Stratified soils
10. Organic soils

* These symbols refer to the classification system of Northcote (1971)

Table 2.2: Textural types of characteristic terrain unit soil associations (from Grant, 1974)

The terrain pattern is recognized mainly from its appearance on aerial photographs with a constant geomorphology and a constant association of terrain units. It is mapped at 1:250000 and represented on an illustrative block diagram, and defined qualitatively in terms of its principal soil, rock, and vegetation characteristics and quantitatively in terms of its lateral and vertical dimensions. The terrain pattern can be regarded as being composed of a limited number of recurring terrain units always associated in the same spatial relationship, and should be coincident with the area represented by a distinctive pattern on an aerial photograph of suitable scale.

The province is also mapped at 1:250000 but relates only to areas

1. Bare, sparse grass, occasional tree or shrub
2. Grassland
3. Shrubland
4. Open woodland
5. Savannah woodland
6. Woodland
7. Forrest
8. Rainforrest
9. Fresh-water swamp forrest
10. Salt-water swamp forrest

Table 2.3: Classes of characteristic terrain unit vegetation formations (from Grant, 1974)

of constant geology as revealed on aerial photographs. It can be defined as an area of constant geology at the group level (Anon, 1973a), composed of a limited number of recurring terrain patterns always associated in the same spatial relationships.

An extensive numerical system of nomenclature has been devised for the classification of provinces, terrain patterns, terrain units and terrain components and standard format sheets for data collection and presentation have been developed.

2.3 The Methodology of P.U.C.E. Surveys

In practice the terrain evaluation process for engineering consists of three phases involving the establishment of the classifications, the quantification or attachment to them of specific engineering

data, and finally the application of the system to particular engineering projects.

The establishment phase is carried out in accordance with the rigorous principles applicable to engineering needs and involves careful selection of terrain classes and boundaries so that they may be uniquely identified and used as vehicles for the communication of engineering data from classifier to user. The latter can then not only use the system as different levels of generalization, but also identify his particular needs within selected terrain classes.

Following the establishment of the classifications the quantitative phase follows by the attachment of engineering information at an appropriate level of detail to the different terrain classes. This is carried out by field testing during which specific soil, vegetation and moisture properties are measured at specific sites. In addition the validity of the topographic land form components are verified by on-site inspection, along with the determination of appropriate terrain parameters. Because of the range and complexity of such information it is collated by a comprehensive system of data storage and presentation (Grant, 1968, 1974), incorporating automated methods (Grant and Lodwick, 1968).

Subsequent to completion of the quantification phase the system is now ready for the needs of the engineer, who can extract from the system sufficient details for, say, mobility assessment or minor road construction, or alternatively information to allow preliminary investigation prior to site selection for more detailed surveys, as necessary for major works.

CHAPTER 3: THE ERTS PROGRAM

3.1 Introduction

The Earth Resources Technology Satellite (ERTS) program has been designed to acquire from satellites orbiting the earth multispectral images of the earth's surface. This data is transmitted through ground stations to a data processing centre at the NASA Goddard Space Flight Centre for conversion into black and white or colour photographs and computer tapes. The two missions so far launched, ERTS1 and ERTS2 provide for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis. The two sensor systems comprise a four channel Multispectral Scanner Subsystem (MSS) and a three camera Return Beam Vidicom (RBV) Subsystem.

The MSS subsystem is used to obtain the binary digital data which is assembled onto Computer Compatible Tapes (CCT) suitable for computer processing and analysis. The RBV camera subsystem contains three individual cameras operating in the nominal specrral bands from 0.475 to 0.830 micrometers. When the cameras are shuttered, the images are stored on the RBV photo sensitive surfaces. These are scanned to produce anologue photographic output. Comprehensive details on the collection and production of ERTS data are contained in the NASA documents Generation and Physical Characteristics of the ERTS MSS System Corrected Computer Compatible Tapes (Anon, 1973b), and Data Users Handbook (Anon, 1972).

3.2 Orbit and Earth Coverage

The ERTS1 satellite is circling the earth in a circular sun-synchronous orbit and provides complete global coverage between 81

degrees north and 81 degrees south latitude. Each day the satellite makes approximately 14 revolutions of the earth. The fifteenth orbit of one day overlaps the first by 1.43 degrees longitude or 159 km at the equator and becomes the first orbit of the next day.

The revolutions progress in a westerly direction so that after 251 revolutions, taking exactly 18 days, a complete coverage cycle is obtained. The next orbit (252) coincides precisely with orbit 1 of the previous cycle. Since the systems operate in the visible wavelengths, they are operative only during daylight sections of the orbit.

3.3 MSS Subsystem

3.3.1 Sensing arrangement

The MSS is a four-band scanner operating in the solar-reflected spectral region from 0.5 to 1.1 micrometers. It consists of six detectors for each of the four bands. The MSS scans swathes of the earth's surface 185 km wide at normal altitude, sensing six scan lines at a time simultaneously for each of the four bands. The sensing of each swathe is accomplished by means of a flat mirror oscillating across the field of view between the ground scene and a double-reflector telescope type of optical chain. Video outputs from each detector in the scanner are sampled, commutated, and multiplexed into a modulated stream which is encoded and transmitted to ground-based receiving sites. The receiving sites compile the raw data on video tapes for calibration and reformatting into usable binary form on computer compatible tapes.

3.3.2 Scanning each scene

Each completed scene is made up of 2340 parallel scan lines, each containing a large number of video data points. Each line scans a

length of 185 km and comprises 3240 individual video data samples. The value of each sample is contained in a byte, made up of eight binary "bits". The value of each byte represents its radiance level. In the linear mode only six bits are used with a range 0 to 63, while in the decompressed mode seven bits are used allowing radiance levels of 0 to 127. The distance covered by a scan line depends on altitude. Experience has shown that in the worst case the altitude variations have resulted in scan line changes of approximately ±4 km. At nominal altitude (918.592 km (496 nm)) the scan line is 185 km long. Figure 3.1 shows the geometry of a completed ground scene.

The scan mirror operates in a scan-and-retrace cycle with the active portion of the scan being in a west-to-east direction. As the spacecraft proceeds along its near polar orbit each subsequent scan and retrace cycle is contiguous with the preceding one. A set of 390 cycles which produces 2340 parallel scan lines provides complete coverage of the full 185 km x 185 km scene.

During the processing phase each scene is subdivided into four parallel strips comprising one quarter of each line. Each strip is presented as one computer tape with data interleaved for all spectral bands.

For ERTS1 reflectance levels in four spectral bands were measured. These bands were in the ranges 0.5 to 0.6 micrometers, 0.6 to 0.7 micrometers, 0.7 to 0.8 micrometers and 0.8 to 1.1 micrometers.

3.3.3 Registration and adjustment of scan lines

The MSS detectors are sampled sequentially at a constant rate of 100.5 kilosamples/sec. with a 2-byte spatial misregistration introduced by the arrangement and sampling sequence of the detectors. This enables

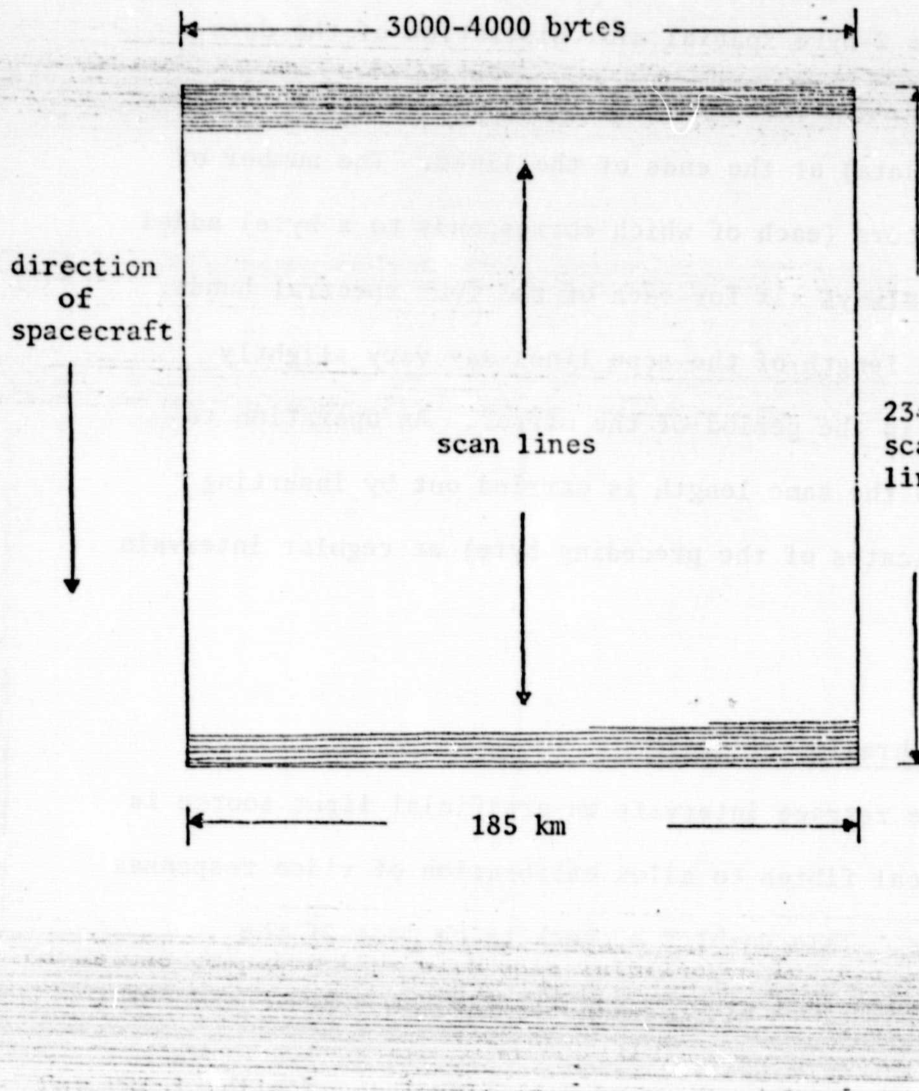

Figure 3.1: Components of a Completed Ground Scene as represented on the MSS CCT.

each ground sample site to be sensed by each of the four bands in turn and means that at the beginning of each scan line only sites from the seventh sample on will be sensed for all four bands. (Similarly at the ends of each line.) This 2-byte spatial misregistration of the data sample is adjusted for by inserting registration fill characters (which contain no useful video data) at the ends of the lines. The number of registration fill characters (each of which corresponds to a byte) added to a given scan line is always six for each of the four spectral bands.

Occasionally the length of the scan lines may vary slightly due to small variations in the period of the mirror. An operation to adjust all scan lines to the same length is carried out by inserting "synthetic" bytes (duplicates of the preceding byte) at regular intervals as needed.

3.3.4 Radiometric calibration of sensors

During alternate retrace intervals an artificial light source is projected into the optical fibres to allow calibration of video responses for the individual bands. This enables a check to be made of the relative radiometric levels, and also to equalize gain changes which may occur in the six detectors of a spectral band. Corrections are performed during preparation of the computer compatible tapes in order to minimize striping within each swathe due to detector differences between lines.

3.4 System Performance

The principal parameters used to indicate the quality of the data are resolution, radiometric fidelity and geometric accuracy. The area of view of each detector is a square section of the surface of the earth with side length 79 metres at normal altitude. Experience has

shown this to be close to the level of cross-track resolution in high contrast areas. In scenes of low contrast the level of resolution is less.

The MSS subsystem is less subject to radiometric inaccuracies than the RBV system because the output of the MSS sensors are in digital form, and therefore not subject to transmission and tape recorder distortions. Fully calibrated MSS data is available without the necessity of intermediate photographic or analogue processes. Errors however may be introduced from electron beam scatter, due to non-uniformity of intensity of the calibrating light source, and due to original errors and long term variation in the calibration coefficients of the lamp/gray wedge system. Typical errors from these sources are in the region of 1-2% of the density range. In addition errors can be introduced during the production of photographic products from MSS tapes. These are in the range of a 2-4% density variation.

Geometric accuracy of the imagery is dependent upon two aspects. These are (a) the positional accuracy or the ability to locate a point in an image in terms of its grid position and (b) the registration accuracy which depends on both the ability to superimpose two points in images of the same area taken at different times and the ability to superimpose two points in different images of a ground scene taken at the same time.

These errors can be introduced externally to the MSS sensing system (spacecraft attitude, orbital errors, exposure time, etc.), or internally (detector alignment, scan non-linearity, sampling uncertainty, etc.), or in data processing (computational precision, flat earth modelling, etc.). For precision output processing the positional mapping accuracy is 242 metres for film products, and the registration accuracy

is 154 metres.

3.5 ERTS Photographs of the Lake Gregory Area

The C.S.I.R.O. Division of Mineral Physics is involved in a project which takes the NASA Computer Compatible Tapes, carries out geometric and radiometric corrections and enhances the data by stretching the contrast of each individual video element. Output is by means of an Optoprix photowrite machine for use by researchers.

Plates 3.1, 3.2, 3.3 and 3.4 show the output and resolution of strip 1, Lake Gregory area (ERTS scene 1564.23594) for bands 4 through 7 respectively.

Plate 3.1: ERTS photograph for band 4 of the Lake Gregory scene.

Plate 3.2: ERTS photograph for band 5 of the Lake Gregory scene.

Plate 3.3: ERTS photograph for band 6 of the Lake Gregory scene.

Plate 3.4: ERTS photograph for band 7 of the Lake Gregory scene.

CHAPTER 4: GEOLOGY AND PHYSIOGRAPHY

4.1 Geology

The area investigated is a section 185 km long by 46.25 km wide centred on Lake Gregory in the north-east of South Australia and comprising parts of the Gason, Kopperamanna and Marree 1:250000 map sheets (Figure 4.1).

All of the area lies within the southern margin of the Great Artesian Basin defined by the proterozoic rocks of the Adelaide System, and consists of Mesozoic, Tertiary and Quaternary deposits.

In the southern half of the strip the Cretaceous deposits of the Rolling Downs Group are overlaid in parts by thin duricrusted Tertiary sediments, interspersed with gently sloping fine and coarser outwash gravels of recent origin. These are dissected by numerous braided streams trending northerly, flowing into the Lake Gregory, Lake Blanche chain of claypans and swamps (see Figure 4.2).

In the north the Quaternary aeolian sand dunes trend north to northwesterly, commonly over 20 miles in length. These are transgressed by the recent alluvial deposits of Cooper's Creek, extending to Lake Eyre.

4.1.1 Cretaceous deposits

The Rolling Downs Group (Whitehouse, 1954) is one of the most widely distributed formations of Cretaceous age in South Australia. All of its larger subdivisions have been identified, and these correspond to the Roma formation (mainly Aptian), the Tambo formation (mainly Albian) and the Upper Cretaceous lagoonal to lacustrine Winton formation (R.C. Sprigg and staff, 1958).

The Marree formation, correlating broadly with the Roma and

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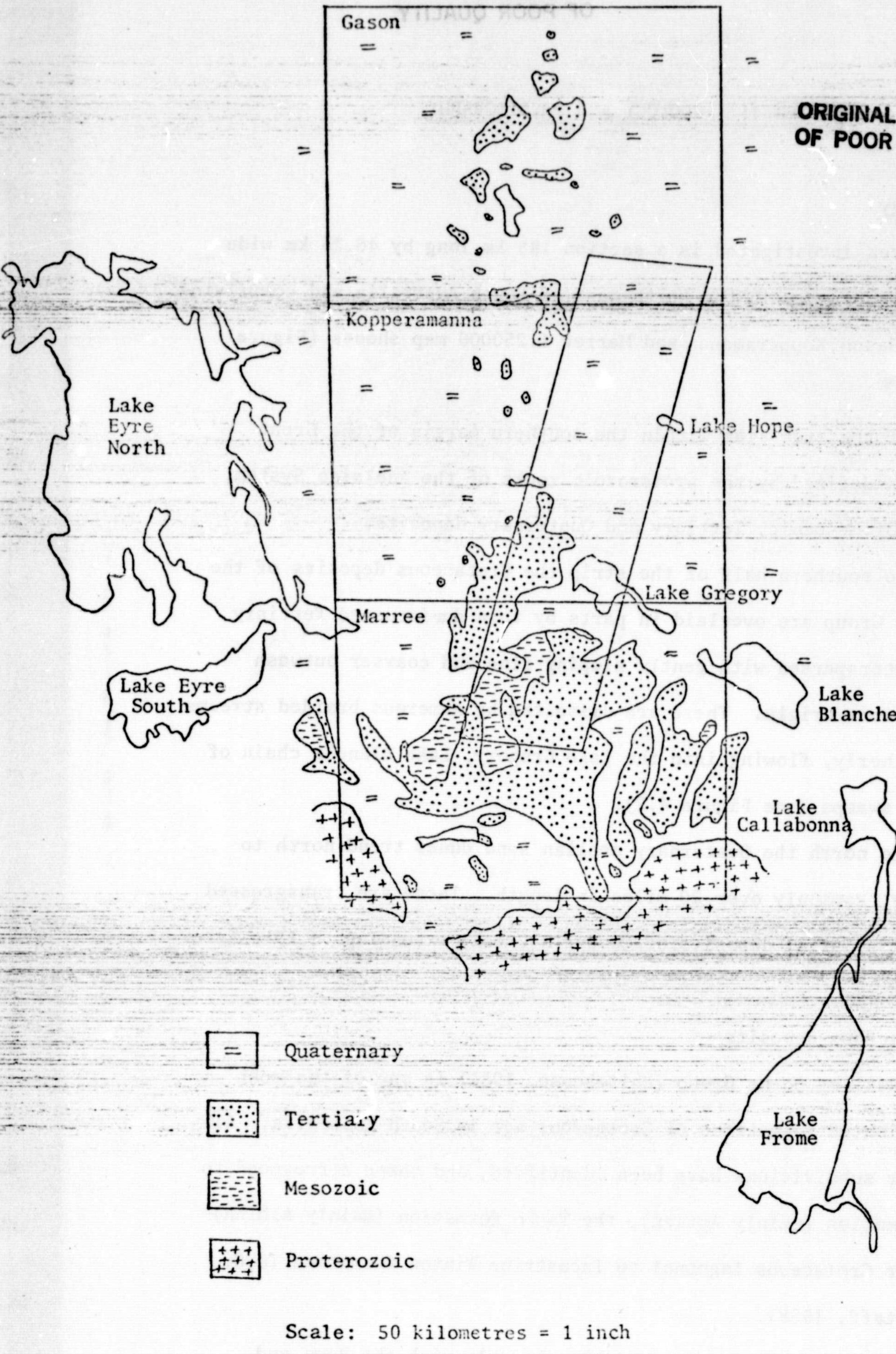


Figure 4.1: Geologic Provinces of Lake Gregory area.

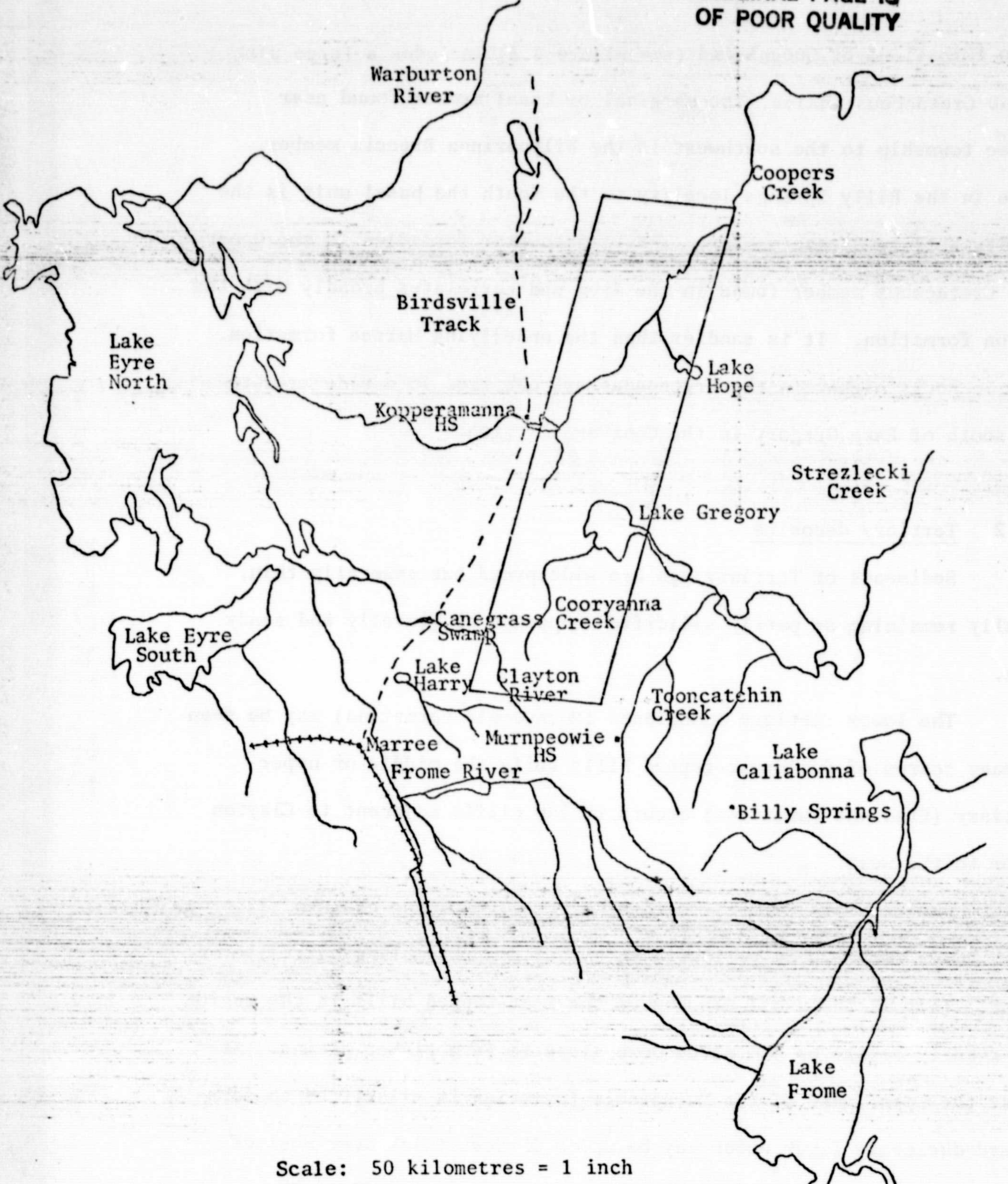


Figure 4.2: Drainage Pattern of Lake Gregory area.

Tambo formations of Queensland (see Figure 4.3) includes a large part of the Cretaceous shales. The marginal or basal member found near Marree township to the southwest is the Wilpoorinna Breccia member, while in the Billy Springs locality to the south the basal unit is the Trinity Well sandstone member. The Blanchewater formation is the uppermost Cretaceous member found in the area and correlates broadly with the Winton formation. It is sandier than the underlying Marree formation.

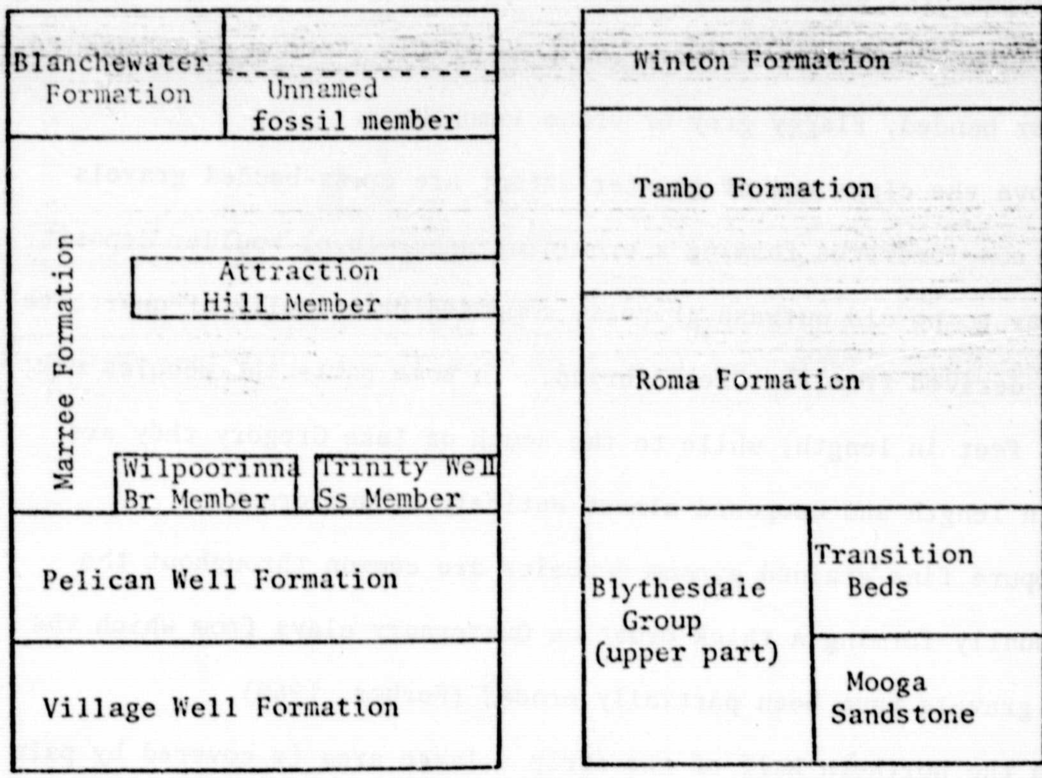
Rocks higher in the Cretaceous are observed in a wide area to the south of Lake Gregory in the Cooryanna region.

4.1.2 Tertiary deposits

Sediments of Tertiary age are widespread but generally thin, usually remaining as partly silicified cappings of gravelly and sandy beds.

The lower Tertiary sandstones (Murnpeowie Formation) may be seen in many scarps of duricrust-capped hills while the middle or upper Tertiary (Etadunna Formation) occurs in low cliffs adjacent to Clayton River to the west.

Duricrust is commonly seen as a hard, very fine grained silicious rock, grey, redbrown or yellowish in colour and resembling quartzite or flint. This is the usual capping of the flat-topped hills in the region, and readily breaks up and moves down slope to form gibber plains. At least the upper part of the Murnpeowie formation is silicified to form a hard duricrust layer which may be up to 25 feet thick over most of the Marree map area. Rocks older than this are rarely affected.



After Forbes (1966)

After Whitehouse (1955) and Vine and Day (1965).

Figure 4.3: Correlation of Mesozoic Stratigraphic Units.

4.1.3 Quaternary deposits

Some of the oldest of these (possibly late Tertiary in age) are grey purple or reddish clays overlying the duricrust as various scattered exposures. In places the clays and overlying older outwash gravels appear to occupy structural depressions. In some places the clay contains thin red sandstone beds while at or near the base of the clays are to be found pisolitic or banded, flaggy grey or cream limestones.

Above the clays and of greater extent are cross-bedded gravels and coarse conglomerates forming a prominent upper-level boulder deposit. These appear to be old outwash gravels, composed principally of quartzite and quartz derived from the Pre-Cambrian. In some parts the pebbles may be up to 2 feet in length, while to the south of Lake Gregory they are 2 inches in length and composed almost entirely of duricrust.

Impure fine grained gypsum deposits are common throughout the region, usually forming a thick crust on Quaternary clays from which the overlying gravels have been partially eroded (Forbes, 1966).

In the northern half of the strip a large area is covered by pale red-brown sand with parallel dune ridges. The dune system trends northerly to north-westerly, is steeper on the eastern slope, and appears to be of longitudinal form (King, 1960). (This dune direction is in contrast to that to the east of Marree where the dunes trend north-westerly. This change in direction reflects the mean position of the anticyclonic system which is dominant over central Australia (Grant, 1976)). Some dunes are over 20 miles in length, and rest on brown silt and clay, sandy in places, and containing soil limestone. The silts probably represent the Quaternary source material from which the sands were winnowed by strong winds. However the bulk of the material forming the sand dunes has been blown out of the alluvial stream deposits. The sand dune expanses are to

be found considerably more well developed on down wind side of the streams (Grant, 1976).

In the southern part of the strip large areas of gently sloping or flat-lying fine gravels have been classified as recent outwash (Forbes, 1966). Recent outwash can also be seen as continuous sheets of coarser gravels near duricrust plateaux. The distinction between lake and stream deposits is artificial and obscure in many localities.

The Cooper's Creek stream deposits in the north, and those of the Lake Gregory-Lake Blanche chain of claypans and swamps in the south contain swamps in addition to more actively-eroded sandy or gravelly channels. Some water holes in deeper channels may carry water for long periods, and areas classified as lakes often include smooth-surfaced claypans, channels and vegetated surfaces (Forbes, 1966).

4.2 Physiography

4.2.1 Surface relief

The area of investigation occurs within the largely arid interior of South Australia, and has an irregular and unreliable rainfall which averages about six inches a year.

In the Great Artesian Basin, eucalypts, commonly coolabah, are confined to large creeks. Vegetation, typified by saltbush, is sparse on the gibber planes or stoney desert, but in sandy areas there is a collection of small trees such as casuarinas, needle bush (Hakea leucoptera) and acacias, including mulga (Acacia aneura).

Relief is generally subdued; hills are typically flat topped and covered by duricrust, higher level gravel or gypsum remnants. The soft-rock pediments flanking the duricrusted residuals have been described in Mabbutt (1969). They are long concave surfaces, which pass

without break into the hillslopes, and they are typically armoured with gibbers from the hill capping. They express the process of slope retreat and piedmont regrading on soft, fine textured rocks to which the term pediplanation has been given. The low gradients reflect the ease of transport of loose sediments across little-vegetated surfaces.

The poorly out-cropping Cretaceous rocks form undulating country flanking the sheets and smaller remnants of duricrust. In this region low gypsum scarps sometimes form prominent land-marks. The lowest recorded elevation of -27 feet is to the west, where the River Clayton enters swamps near Lake Eyre. Further out in the Artesian Basin large areas are covered by sand ridges and gravel plains.

4.2.2 Sand dunes

The dune form of parallel ridges has been reported in detail by Mabbutt (1968a). They are characteristic of large, open expanses of dunes where sand movement has been least complicated by relief or drainage. They are mainly between 10 metres and 25 metres high with a typical spacing of between 300 and 500 metres. The spacing and height tend to be uniform and indicative of equilibrium relationships. The ridges usually have smooth middle and lower flanks stabilized by closer grass cover with spinifex (Triodia basedowii) predominant, and uneven crests with more mobile sand and a scantier vegetation with canegrass (Zyochloa) and shrubs.

The stabilized lower body of the dune is characteristically asymetrical with a gentler western flank, and a steeper eastern flank; a crestal belt of live sand 25 to 50 metres wide rests upon the stable lower portion.

The swales are generally sandy, with uneven loose sand between

the arms of junctions, but there are flat tops with claypans locally and areas of gravel outcrop. In most cases the sub-aeolian floor is a little below the level of the swale (Mabbutt and Sullivan, 1968). Between the dunes are small playas, occasionally filled with salt water.

In the north, the sand ridges are dissected by Cooper's Creek trending south-west to Lake Eyre.

4.2.3 Drainage

The drainage type in the area falls into the classification of co-ordinated interior drainage (Hills, 1953), of which the Great Artesian Basin is the only important example in Australia (Mabbutt, 1969). It results from the structural disposition of peripheral uplands on uniform soft sedimentary rocks, but is also reflective of the pattern of greater and more effective rainfall north-eastwards, towards the upland catchments.

In the southern half of the strip, there are two main directions of drainage, to the north-west into the Lake Eyre basin and to the north-east into the Lake Gregory-Lake Blanche chain of claypans and swamps.

Along the Birdsville track, creeks drain the western limb of the Cooryanna dome and make their way into shallow depressions such as Canegrass Swamp and Lake Harry which occur in a zone along the western limb of the structure.

To the east, Tooncatchyin Creek occupies a structural depression between the Cooryanna dome and the duricrust plateau south of Lake Blanche. The Lake Blanche system of claypans is analogous to the Lake Harry zone, but is much more strongly aligned.

CHAPTER 5: TERRAIN CLASSIFICATION FOR ENGINEERING OF THE LAKE GREGORY AREA

Classification of the Lake Gregory area was carried out by the Division of Soil Mechanics, C.S.I.R.O. in 1967. The strip of ERTS image investigated comprises parts of the Marree, Kopperamanna and Gason 1:250000 map sheets.

Four provinces are included in the strip

province 43.001 (Rolling Downs Group)

province 52.001 (alluvium)

province 52.002 (aeolian sand)

province 52.008 (more recent alluvium, colluvium)

and the terrain pattern details for these are given in Tables 5.1, 5.2, 5.3 and 5.4.

Plate 5.1 shows the terrain pattern classification map of the area (Grant, 1970 a,b,c). The differentiation of the map into the various provinces is as follows:

Province 43.001 consists of six terrain patterns of which the four defining flat to undulating terrain are coloured blue. (Two of these are of limited extent.) The two representing the dissected higher surfaces correspond to the pink shades.

Province 52.001 is the yellowish green band trending north-westerly and transecting the northern half of the strip. It consists of a single terrain pattern corresponding to the alluvial deposits of Cooper's Creek.

Province 52.002 is defined by the area in yellow, and consists of a single terrain pattern made up of extensive sand dune formations.

Province 52.008 is coloured green, and consists of three terrain

Province No. 43.001: Age: Cretaceous (may be overlain in part by a veneer of tertiary or quaternary rocks)
Group: Rolling Downs
Lithology: Claystone, siltstone, sandstone, shale, some limestone, sometimes ferruginized (ferruginous sandstone or ironstone) and/or silicified (silcrete, porcellanite or opal) (may include a veneer of tertiary or quaternary rock on higher surfaces)

0 Topography: Flat to undulating terrain

Terrain pattern No.	Topography	Rock condition	Earthen materials: Profile	Earthen materials: Surface cover	Vegetation
01/2	Flat to gently undulating terrain sometimes bounded by a low escarpment	Consolidated partly silicified	Yellow or red fluffy gypsiferous clay mostly overlying kopi or decomposed or silicified rock	Dense silcrete	Bare
01/3	Gently undulating terrain with occasional low escarpments	Consolidated; sometimes ferruginized	Shallow red or brown medium-textured clay mostly overlying kopi and decomposed rock	Silcrete	Mostly bare
03/1	Undulating dissection slopes with occasional low hills	Consolidated; sometimes ferruginized	Shallow silty gypsiferous clay on higher slopes, yellow or red medium-textured clay overlying decomposed rock downslope	Silcrete	Mostly bare
03/2	Undulating terrain often bounded by low dissected slopes	Consolidated; occasionally silicified	Shallow yellow or red medium-textured clay mostly over kopi and decomposed rock	Dense silcrete	Mostly bare
	1 Topography: Dissected higher surface with associated surrounding undulating low surface				
11	Gently undulating terrain often bounded by steep escarpments, sometimes bounded by dissection slopes	Consolidated: sometimes silicified	Mostly red or brown medium-textured clay over decomposed rock; some silcrete outcrop	Silcrete	Mostly bare

Province No. 43.001 (cont)

Terrain pattern No.	Topography	Rock condition	Earthern materials: Profile	Earthern materials: Surface cover	Vegetation
16	Eroded dissected terrain (mesas, buttes, cuestas) with associated surrounded undulating terrain	Consolidated; sometimes ferruginized; silicified on upper surface remnants	Shallow yellow-red silty clay with silcrete outcrop on higher surface remnants; brown medium-textured clay on lower surface	Silcrete	Mostly bare

Table 5.1: Province No. 43.001 (from Grant, 1970 a,b,c)

Province No. 52.001

Age: Quaternary
Group: Alluvial - major drainage of province 43.001 (Diamantina, Warburton Rivers, Cooper Creek)
Lithology: Clay, silt, some sand
1 Topography: Flat to gently undulating surface with incised channel

Terrain pattern No.	Topography	Rock condition	Earthen materials: Profile	Earthen materials: Surface cover	Vegetation
11/3	Gently undulating terrain overlain in part by aeolian sand containing incised discontinuous river channel	Unconsolidated	Mostly stratified grey or yellow sand, clay	Nil	Mostly bare

Table 5.2: Province No. 52.001 (from Grant, 1970 a,b,c)

Province No. 52.002: Age: Quaternary
Group: Aeolian sand
Lithology: Sand
1 Topography: Sand dunes with associated inter-dunal flats and playas

Terrain pattern No.	Topography	Rock condition	Earthern materials: Profile	Earthern materials: Surface cover	Vegetation
11	Linear sand dunes with associated inter-dunal areas and playas	Unconsolidated	Dune sand on dunes; medium-textured clay, often sandy, in inter-dunal areas	Nil on dunes; some silcrete in inter-dunal areas, salt on playas	Mostly bare, some cane grass

Table 5.3: Province No. 52.002 (from Grant, 1970 a,b,c)

Province No. 52.008: Age: Quaternary
Group: Alluvium, colluvium associated with province 43.001
Lithology: Clay, silty clay
0 Topography: Flat to undulating terrain

Terrain pattern No.	Topography	Rock condition	Earthern materials: Profile	Earthern materials: Surface cover	Vegetation
00	Flat terrain; shallow lake beds	Unconsolidated	Stratified clay	Mostly nil, some crystalline halite, gypsum	Mostly bare
01	Flat terrain	Unconsolidated	Brown-yellow silty clay, some sand, gravel	Silcrete	Mostly bare
06	System of single and braided channels with associated floodplains	Unconsolidated	Mostly yellow medium-textured clay, often stratified	Silcrete	Mostly bare

Table 5.4: Province No. 52.008 (from Grant, 1970 a,b,c)

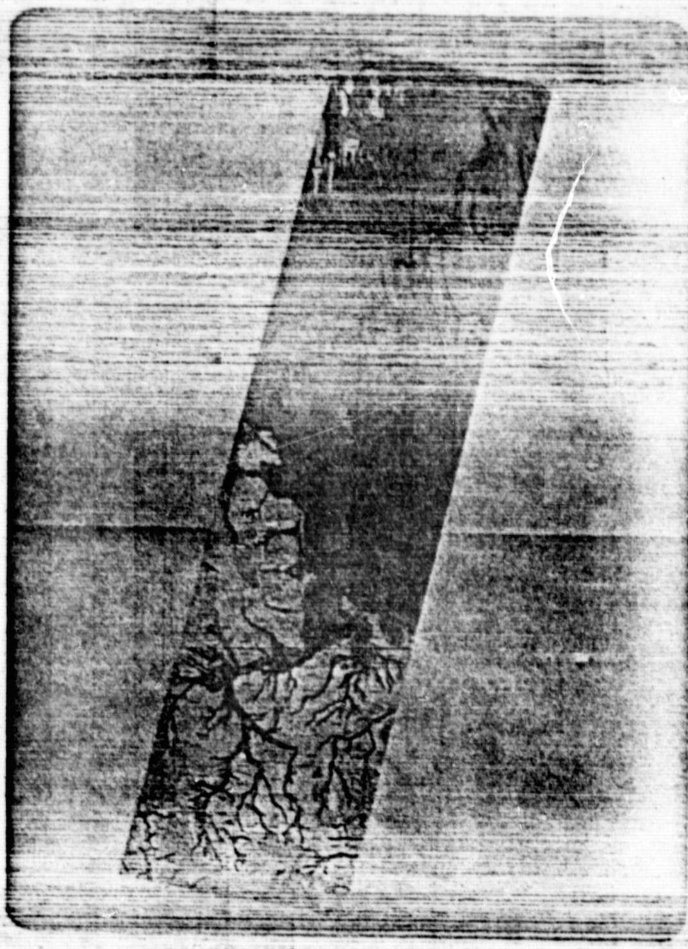


Plate 5.1 : Terrain classification pattern map corresponding to strip 1 of the Lake Gregory scene.

patterns representing the drainage channels and lakes related to the Rolling Downs Group. The light green defines the pattern corresponding to the shallow lake beds while the dark green tones refer to the systems of channels and floodplains.

CHAPTER 6: TECHNIQUES OF MULTIVARIATE ANALYSIS

6.1 Introduction

A number of approaches are possible in the analysis and interpretation of the ERTS data. Two of these are

(a) use of mathematical methods such as factor analysis and cluster analysis, and

(b) analysis by 'signatures'.

The first method involves mathematical manipulations and transformations to endeavour to enhance the data to a stage where underlying correlations and patterns can be easily identified.

The second method depends on a careful selection of 'signature' areas so that the properties of individual attributes can be identified. The attributes for all video elements can then be compared to the 'signature' set to determine the classification for the whole map area. This approach, however, inevitably leads to dual classification of some elements and non-classification of others. It also has two important areas of difficulty.

Firstly, by defining 'signatures' it is necessary to be certain that a particular area is really typical of the type of terrain being defined and that each 'signature' is defined once and only once for all separate classes of terrain. This requires that the interpretative phase of definition of meaningful attributes is a first step in the agglomeration of classifications, and presupposes considerable knowledge of the area being investigated.

Secondly this approach also lends itself less well to wide-scale terrain analysis. For example 'signatures' of identical pieces of terrain will be different for different ERTS scenes (due to sun angle, time of

year, different surface conditions, etc.), which will mean that for each scene it will be necessary to define a complete reference set of 'signatures' for comparison purposes.

The analytical approach on the other hand highlights differences in pattern and terrain with a basic technique independent of the individual scene and leaves the interpretative phase as the last stage in the process, i.e. until the time when maximum knowledge of the data is available. At such a stage it will be easier to define meaningful class attributes and to determine the number of naturally occurring classes.

6.2 Standardization

Standardization of data is an important procedure in factor analysis and cluster analysis techniques and may greatly influence the results. If it is carried out by subtracting from each observation the mean of the data set and dividing by the standard deviation, so that the transformed set of data has a mean of zero and a variance of one. The value of each original observation will then be measured in terms of its standard deviation from the mean. This is a very useful procedure for comparing the distribution of one variable with another when the two variables are expressed in different units of measurement or extend over different ranges.

In practice, because factor analysis is concerned with analysing the structure of the variance-covariance matrix, standardization of each individual observation is not necessary before computation, since the covariance matrix of standardized variables is the same as the correlation matrix (Moroney, 1951; p.287).

6.3 Factor Analysis

Factor analysis methods have been developed to assist in the resolution of multivariate problems, such as those in geology where 10 attributes (say) may be measured on a number of samples. What is sought are methods of ordering the samples so that relationships between one sample and another can be readily identified. Factor analysis techniques simplify such problems by transforming the original data set onto the minimum number of significant linearly independent variables.

The method involved is to set up a variance-covariance matrix of the multivariate data set and recalculate scores for the samples along the principal components, which represent the new variables.

There are two categories of factor analysis, (a) principal components analysis and (b) factor analysis itself, of which principal components analysis was chosen as the preferred technique because in application, it does not require initial assumptions concerning the number of underlying linearly independent factors (see below).

6.3.1 Principal component analysis

Principal components are simply the eigenvectors of a variance-covariance matrix.

Suppose m variables are measured on a collection of objects. Then an m x m matrix of variances and covariances can be computed, from which can be extracted m eigenvectors and m eigenvalues. Because a variance-covariance matrix is always symmetrical, these m eigenvectors will be orthogonal, or oriented at right angles to each other, and therefore linearly independent.

The total variance in our data set can be defined as the sum of the individual variances, which in a variance-covariance matrix, are

represented by the diagonal elements. The trace of the matrix is defined as the sum of these elements and is equal to the sum of the eigenvalues which represent the lengths of the principal axes. It follows therefore that these principal axes also represent the total variance of the data set, with each accounting for an amount of the total variance equal to the eigenvalue divided by the trace. Thus, if the variation in the data set is measured along the first principal axis, the resulting scores will represent a proportion of the total variation in the original observations.

The value of principal components analysis thus lies in enabling the selection of a minimum number of new variables which will account for a sufficient amount of the original variance. The linear transformation of the m original variables into m new variables is performed in such a way that each successive new variable accounts for as much of the total remaining variance as possible. If all of the m new variables are computed, the total original variance will be accounted for.

In practice PCA is a mathematical manipulation rather than a statistical procedure, and its usefulness is judged more by performance than by theoretical considerations. However, it assumes some of the characteristics of statistical procedures when decisions are made to discard some new variables whose contribution to the variance is considered to be inconsequentially small (Davis, 1973; p.501). Some tests of significance have been developed but these are based on highly restrictive assumptions (refer Morrison, 1967; pp.247-254).

6.3.2 Factor analysis

Factor analysis is different from principal components analysis in that it is considered to be a statistical technique and relies on an

initial set of assumptions about the nature of the parent population from which the samples were drawn. These are that the relationships within a set of m variables reflect the correlations of each of these variables with p mutually uncorrelated underlying factors where usually $p < m$. Thus the variance in the m variables is derived from variance in the p factors, but in addition a contribution is made by unique sources which independently affect the m original variables (Davis, 1973; p.502).

In order therefore to undertake a factor analysis it is necessary that p, the number of factors, be known prior to analysis. This implies that the investigator has some insight into the probable nature of the factors, so that these can be extracted, and the contribution of the unique sources isolated.

Factor analysis consists of two procedures - R-mode and Q-mode factor analysis. R-mode factor analysis investigates interrelations in a matrix of correlations between variables. The factors which are created are new variables, formed as a linear transformation of the original variables. The approach is similar to that of principal components analysis in that each sample is redefined in terms of its factor (or principal component) scores. Q-mode analysis on the other hand is concerned with interrelationships between samples. Objectives of Q-mode analysis are much the same as the objectives of cluster analysis (see later) which are to arrange a suite of samples into a meaningful order so the relationship between one sample and another may be deduced. A discussion of the various types of factor analyses is given by Cattell (1965, pp 411-423), while Lawley and Maxwell (1963, Chapter 2) discuss significance tests in factor analysis.

6.4 Cluster Analysis

Cluster analysis involves the placing of objects into homogeneous groups on the basis of individual characteristics or similarities so that any relationships between groups is revealed.

With the advent of the computer, methods of numerical analysis have assumed increasing importance over the analytical and interpretative approach of the individual specialist. Basically there are two approaches which can be employed in cluster analysis. These are (a) agglomerative classification and (b) divisive classification.

6.4.1 Agglomerative classification

The approach of agglomerative classification is that individuals are progressively fused into complete populations on the basis of a selected measure of similarity.

Suppose there are a collection of objects which are to be arranged into a hierarchical classification. On each object, a series of measurements can be made which constitute the data set. If m characteristics are measured on n objects, the data set forms an n x m matrix which can be used to calculate a measure of resemblance or similarity between every pair of objects. Several coefficients of resemblance (c_{ij}) can be used, including the correlation coefficient (r_{ij}) and a standardized m-space Euclidian distance, d_{ij}, computed by

$$d_{ij} = \sqrt{\frac{\sum_{k=1}^{m} (X_{ik} - X_{jk})^2}{m}}$$

where X_{ik} denotes the kth variable measured on object i and X_{jk} is the kth variable measured on object j. In all, m variables are measured on each object, and d_{ij} is the distance between object i and object j. A

low distance d_{ij} indicates the two objects are similar or "close together", whereas a large distance indicates dissimilarity (Davis, 1973; p.457).

Computation of a similarity measurement between all possible pairs of objects results in an n x n similarity matrix with any coefficient c_{ij} giving the resemblance between objects i and j. By arranging the objects into a hierarchy so that objects with the highest mutual similarity are placed together then each of the objects becomes associated with others which it most closely resembles.

In order to join the objects into groups beyond the first level of association several techniques have been developed and these are discussed at length in books by Tryon and Bailey (1970), and Sokal and Sneath (1963). One simple technique is the weighted pair-group method with arithmetic averages.

In this scheme the next step is to find the mutually highest correlations in the matrix of coefficients. Any two objects which form mutually high pairs (whose coefficients c_{ij} and c_{ji} are the highest) are joined and their new correlations with all other objects calculated simply by arithmetic averaging. The similarity matrix is then recomputed, treating grouped or clustered elements as a single element.

This procedure is then repeated by reclustering mutually high pairs until all clusters are joined together.

6.4.2 Divisive classification

In practice agglomerative methods such as outlined above when used for classification by digital computer suffer from three disadvantages. First, the process begins at the inter-individual level, where information is minimal and the possibility of error high, and in a

hierarchical procedure fusions once made are irrevocable, no matter how unfortunate they may later appear to be.

Secondly, for n individuals the process begins with the calculation of all $\frac{1}{2}n(n-1)$ inter-individual measures and when n is large as is often the case, the programs tend to be time consuming and computationally expensive.

Finally, it is necessary to compute the complete hierarchy (in most cases requiring $(n-1)^2$ calculations) when usually only the last few intergroup fusions are all that is required.

An alternate approach, also effective in terms of producing meaningful classifications is a divisive strategy, whereby the complete population is progressively divided (in practice always dichotomously) until a desired level of subdivision is attained.

A practical example is program POLYDIV, a divisive clustering program develcped by Williams and Lance (1975), for use with all-numeric data. This acts by reference to all attributes simultaneously.

In a divisive approach the first procedure is to extract the eigenvectors from the standardized data-matrix of correlations. Next a string of scores, one for each individual is calculated on the first principal component. This string is ordered and divided into two subgroups at the point where the between-group sum of squares (of deviations from the mean) is maximum. Each sub-group is now treated exactly as was the primary population and by repeating the process the number of groups required can be obtained.

CHAPTER 7: COMPUTER TECHNIQUES

7.1 Introduction

Analysis of the IBM compatible ERTS tapes was carried out using programs specially written for this investigation, or adapted from standard subroutines. The analysis was a multistage process consisting of the development of

(a) routines to output the results pictorially on a line printer,

(b) routines to reformat the IBM compatible ERTS tapes into CDC Cyber compatible mode,

(c) routines for determination of statistical properties of the data,

(d) methods to correct and filter the original data,

(e) programs to carry out a principal component analysis of the data to assist with evaluation and classification, and

(f) techniques to allow application of cluster analysis procedures.

7.2 Presentation of results

For purposes of comparison and interpretation of the data the most convenient presentation was pictorially or graphically. This would enable direct correlation to the base 1:250000 terrain pattern map being used as 'ground truth'. What was needed was a fast, reliable, accurate and reproducible method which could differentiate the results sufficiently to allow this to be carried out.

A suitable solution involved the use of shade-prints. Macleod (1970) developed an improved technique for the production of pictorial output on a computer line printer based on an earlier technique

by Perry and Mendelson (1964). Using this method a reasonable black-white contrast ratio can be obtained by overprinting up to eight characters.

The possible character positions on a line printer may be considered as cells in a two-dimensional array. (On the standard CDC printer this array has a width of 136 character positions without limitation on length.)

By choosing the character (or combination of overprinted characters) printed in each cell on the basis of average print density, a pictorial representation of any desired two-dimensional data may be generated. However there are limitations to this technique, viz. that the maximum number of horizontal characters in a line of print restricts the horizontal size of the picture (unless it is assembled from several strips) and also such pictures will be inferior to those produced by special purpose hardware. Nevertheless the convenience and ready availability of a line printer is in many cases sufficient advantage to outweigh loss of quality (e.g. McCloy (1976) implemented techniques for the generation of gray scale pictures on a Calcomp plotter. This produced higher quality output than shade prints because each element could be plotted contiguous with those adjacent whereas in the case of a shade print the inter hammer positions remain white. However small plots sized twenty by fifteen cm took over two hours to generate which for this investigation was considered impracticable.)

The print output was produced on a CDC 512 line printer using a well inked ribbon and medium print pressure.

The density code values as used by Macleod were initially selected and resulted in twenty one density levels, as set out in Table 7.1.

Character codes	Reading 1	Reading 2	Reading 3	Reading 4	Selected
blank	0.00	0.00	0.00	0.00	*
-	0.05	0.07	0.05	0.05	*
=	0.06	0.07	0.06	0.06	
+	0.06	0.08	0.05	0.08	
)	0.06	0.08	0.06	0.08	
1	0.06	0.10	0.10	0.10	
Z	0.07	0.09	0.10	0.10	
X	0.08	0.10	0.08	0.10	
A	0.08	0.12	0.12	0.13	*
M	0.10	0.12	0.10	0.11	
O-	0.14	0.15	0.17	0.15	
O=	0.14	0.17	0.19	0.15	*
O+	0.18	0.19	0.22	0.19	
O+'	0.18	0.20	0.24	0.20	*
O+'.	0.22	0.23	0.31	0.24	*
O+'.=	0.26	0.32	0.35	0.29	
OX'.-	0.28	0.33	0.32	0.32	*
OX'.HC	0.34	0.36	0.40	0.36	*
OX'.HB	0.33	0.36	0.43	0.42	
OX'.HBV	0.34	0.41	0.37	0.41	
OX'.HBVA	0.40	0.42	0.43	0.46	*

Table 7.1: Selected character codes showing density levels

A sample printout was run off which consisted of adjacent stripes of the selected levels on a page of output (Figure 7.1) and an evaluation of the gray level for each stripe was carried out using a Baldwin reflection densitometer from C.S.I.R.O. National Measurement Laboratory, Chippendale, N.S.W. The densitometer was able to integrate the reflectance values over a circular aperture of diameter three-sixteenth of an inch.

Four independent readings were taken for each band with the results printed out in Table 7.1 and plotted in Figure 7.2.

These show that there is a gradual gradation in gray level from white to the most dense value which in combination with the inter hammer spaces results in a measured density value of .43.

Visual experiment with the character codes indicated that nine were adequate to give a reasonable picture definition. The codes chosen were at approximately equal spacings on the density scale and are indicated by an asterisk in Table 7.1.

In addition to providing shade prints, the option was included to print out actual values (of members of the full Cyber character set from 0 to 63), so that individual analysis of a specific map or hand contouring of particular sections of the output could be easily carried out.

The computer routine written to produce the original 21 levels is printed out in Appendix 1.

7.3 Reformatting the ERTS Tapes

The ERTS tapes consist of IBM compatible 9-track, 800 bpi, mixed binary and EBCDIC coded tapes. A scene is divided into four strips comprising one file each and packed two to a tape. Thus one physical

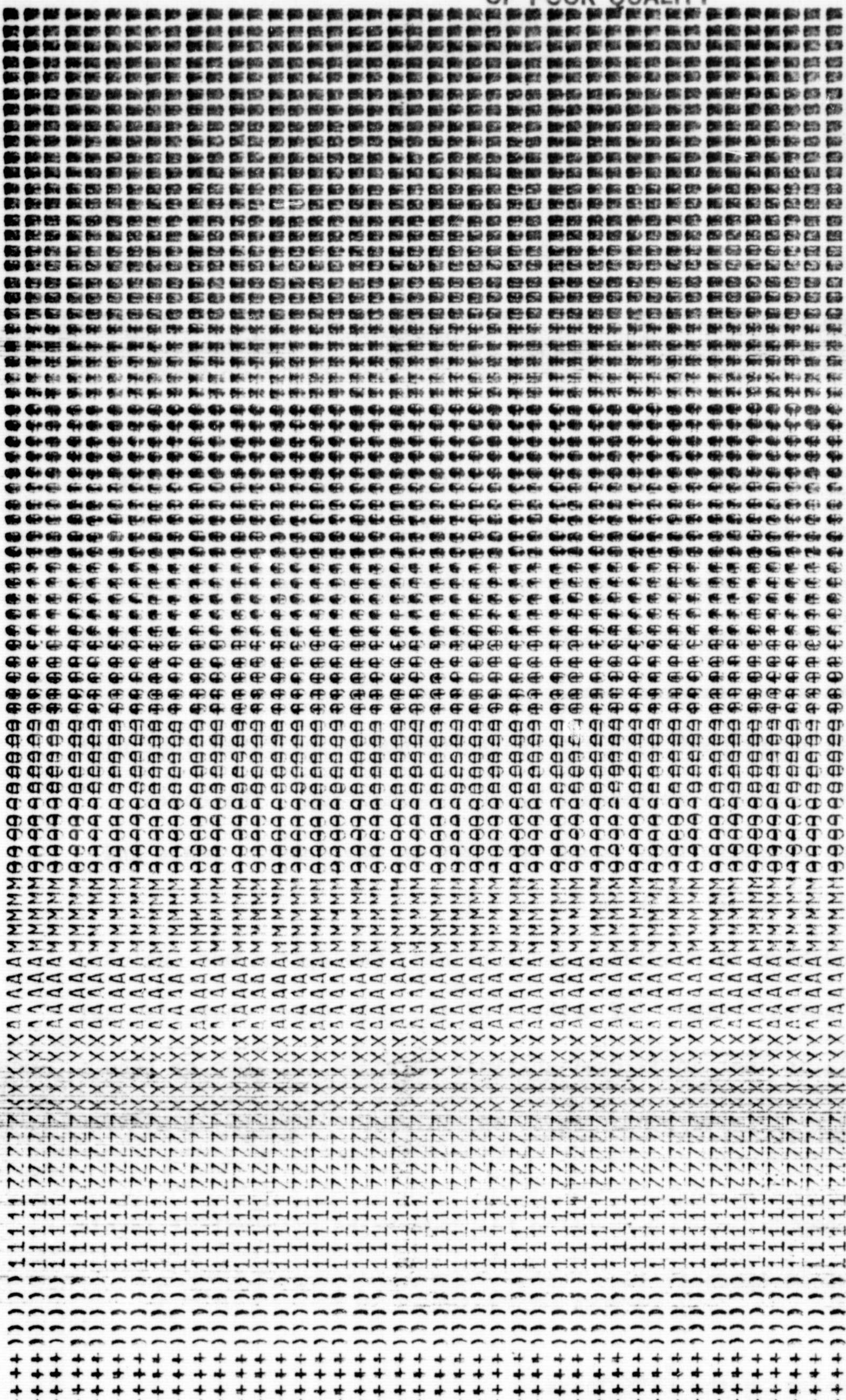


Figure 7.1: Shade print of selected character codes.

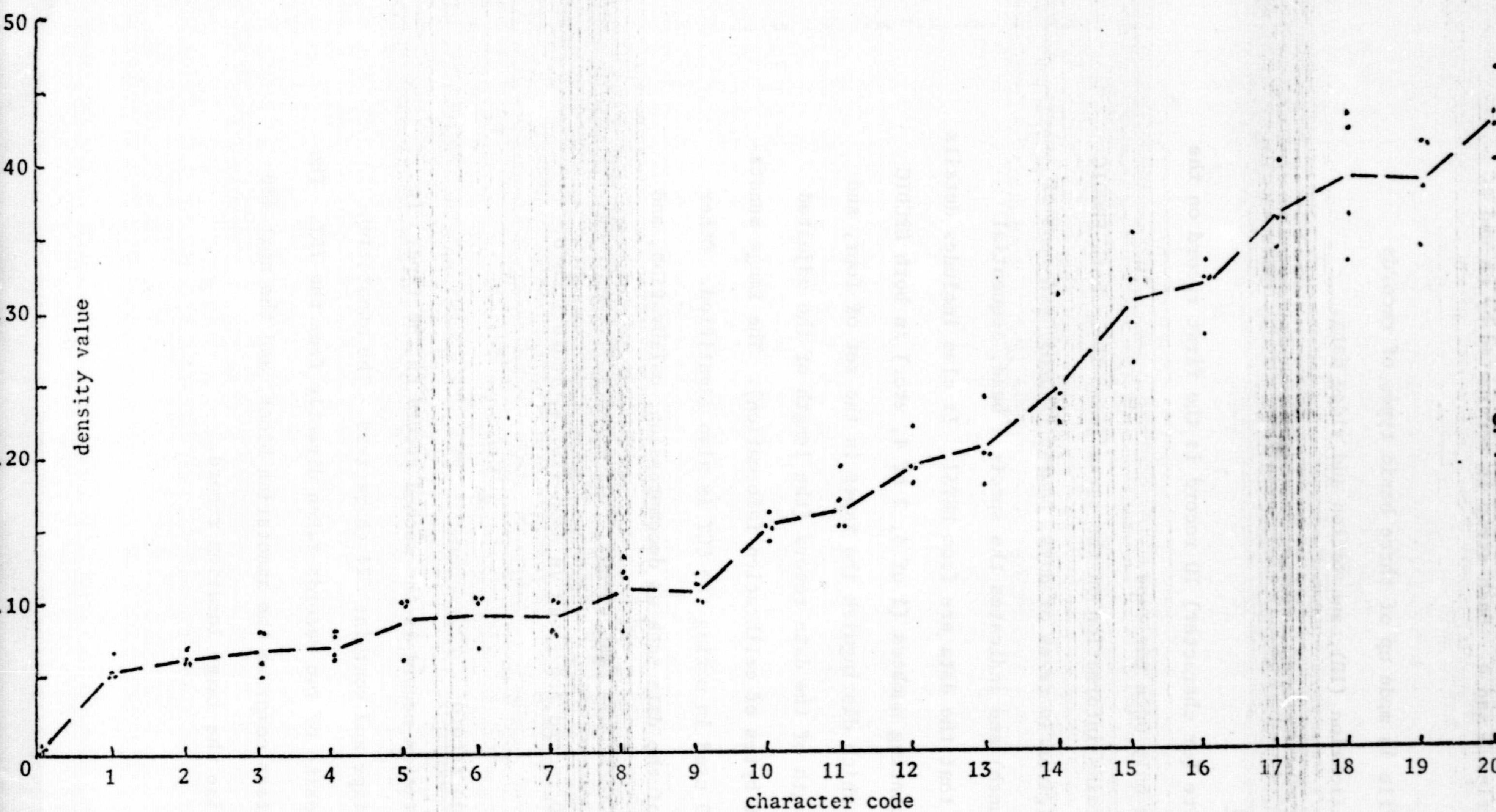


Figure 7.2: Density values for selected character codes.

tape consists of strip 1 and strip 2 of a scene, and a second physical tape comprises strips 3 and 4. Each strip is terminated by an end of file marker.

The MSS file is made up of three basic types of records containing identification (ID), annotation and video data.

7.3.1 ID record

The 40-byte (or character) ID record is the first record on the tape, and appears only once per tape.

This contains information on the scene/frame ID in both EBCDIC and binary code (given in terms of days, hours, minutes, and tens of seconds since launch) and indicates the spectral band, sequential subframe ID, and that the data are from ERTS1. It also includes details on the strip sequencing numbers (1 of 4, 2 of 4, etc.) in both EBCDIC and binary code, which distinguish the tapes in the set of four, and indicates the length of the data record (the length of the adjusted scan line plus 56 bytes of calibration information). The image annotation tape (IAT)ID used in making the CCT is also identified. Other characteristics of the data such as decompression, calibration, and line length adjustment are also given. Full details of the format and content of the ID record are given in Anon (1972), Table 1, p.6.

7.3.2 Annotation record

The annotation record is the second record on the tape. It occurs once per tape and contains 624 characters. The annotation record is a composite of two records taken directly from the IAT. The first 144 characters comprise the annotation block, and the next 480 characters comprise the image location record.

The information included in the annotation data block is specified at the time of RBV exposure or at the centre of the MSS frame. The format and content of the characters are defined in detail in Anon (1972), Table 2, p.11. This block includes details on time of exposure, latitude and longitude co-ordinates, sun elevation and azimuth information, orbital path, photographic settings and processing methods.

The image location data describe the tick marks that associate the scene with latitude and longitude. There can be a maximum of six tick marks per side (i.e. left side, right side, top and bottom).

7.3.3 Video data record

The basic element in the video data record, the data word, consists of eight bits, of which seven are used if the data mode is decompressed (bands 4,5,6) and six for linear mode (band 7). The following illustrates the data word for the two modes:

Linear: 00XXXXXX Decompressed: 0XXXXXXX

The X's represent the video data bits in the word (either one or zero), giving a range from 0 to 127 in the decompressed and 0 to 63 in the linear mode. Individual values represent the variation of the radiance level (0 represents black, 63 or 127 as appropriate represent white, and the values in between represent all the shades of gray). Special values indicate flags (11111111 or 255, is used as the registration fill character).

In order to obtain a video data record which includes information from all four spectral bands, the data from the bands are grouped together in a process called interleaving. This is an operation in which two bytes of data from each band are interleaved to produce an

eight-byte "group", which is the smallest element of interleaved data. Each pair of data samples in the group represent the same two points on the ground, for each of the four spectral bands.

As discussed above registration fill characters are included in the first and last three groups (the first three groups of each quarter scan line on tape 1 of 4 and the last three groups of each quarter scan line on tape 4 of 4).

Thus the first and last three groups are respectively

00 00 00 XX   00 00 XX XX   00 XX XX XX   and

XX XX XX 00   XX XX 00 00   XX 00 00 00

where the 0's represent fill characters.

For this scene the line length was 3240 bytes per band or 810 bytes per strip which, when interleaved, produced 405 groups per line.

In addition to these 405 eight-byte groups the ERTS1 video data record consists of a further four 14-byte calibration groups. These contain calibration data for each of the four MSS bands. Each group contains six calibration wedge samples, a sun calibration coefficient, correction coefficients (filtered offset and filtered gain), and the value of the unadjusted line length for a band.

7.3.4 Computer program for reformatting

Before the video data could be read on the Cyber 72 an intermediate stage of reformatting was necessary because the Cyber word size consists of 6-bit characters, whereas the IBM mode comprises 8-bit characters. A 6-bit character means that only the values from 0 to 63 can be represented whereas 8-bit characters have a range of 0 to 255. In fact the video data coded on the MSS CCT's has a valid range of only 0 to 127 because of the use of 7 bits only.

A standard package is available on the Cyber to translate)IC 8-bit code into Cyber 6-bit code, but this only carries out a -to-one mapping of the 64 common EBCDIC codes (the alphabet, digits common symbols which have discrete values but do not comprise the 0-63). Thus preprocessing was necessary to map the video codes nge 0 to 127 decompressed (bands 4,5,6) and 0 to 63 linear (band 7)) o a maximum 64 codes spread within the range 0 to 255, for translation o a 0 to 63 Cyber set. However there were two complications. First y 63 of the 64 Cyber codes are discrete, code 51 being identical to le 0 due to the magnetic tape handling characteristics. Secondly in lition to the valid video values it was necessary to allow for ırious values outside the range (e.g. registration characters).

The original values were therefore mapped to the necessary set 63 by halving the decompressed values and combining 0,1 and 62,63 well as values outside the range to single values. When these coded values were input to the Cyber the EBCDIC conversion routine ıen translated the values to the required 63 codes as set out in Table 2. (The question as to whether halving the decompressed data does in ıct result in some loss of information is an interesting one. All ınds are actually read by satellite in the range 0 to 63, but bands ,5,6 are decompressed during processing by NASA to range 0 to 127. cCloy (1976) has produced cumulative frequency tables for individual ata elements for the decompressed bands which reveal a stepping effect ased on adjacent levels. When adjacent pairs of values are combined o form a 64 level set this effect disappears to give a smoother distri-ution. This leads him to suggest that decompression of the bands is ın artificial process which does not lead to conveying more information.)

The reformatting program also checked the ID record and the ANNOTATION record which were printed out for confirmation but not trans-

Original value				Original value			
Decompressed	Linear	Cyber value	Cyber code	Decompressed	Linear	Cyber value	Cyber code
0,1,2,3	0,1	51	:	66,67	33	32	5
4,5	2	1	A	68,69	34	33	6
6,7	3	2	B	70,71	35	34	7
8,9	4	3	C	72,73	36	35	8
10,11	5	4	D	74,75	37	36	9
12,13	6	5	E	76,77	38	37	+
14,15	7	6	F	78,79	39	38	-
16,17	8	7	G	80,81	40	39	*
18,19	9	8	H	82,83	41	40	/
20,21	10	9	I	84,85	42	41	(
22,23	11	10	J	86,87	43	42	)
24,25	12	11	K	88,89	44	43	$
26,27	13	12	L	90,91	45	44	=
28,29	14	13	M	92,93	46	45	b
30,31	15	14	N	94,95	47	46	,
32,33	16	15	O	96,97	48	47	.
34,35	17	16	P	98,99	49	48	"
36,37	18	17	Q	100,101	50	49	[
38,39	19	18	R	102,103	51	50	]
40,41	20	19	S	104,105	52	52	'
42,43	21	20	T	106,107	53	53	&
44,45	22	21	U	108,109	54	54	!
46,47	23	22	V	110,111	55	55	@
48,49	24	23	W	112,113	56	56	^
50,51	25	24	X	114,115	57	57	#
52,53	26	25	Y	116,117	58	58	<
54,55	27	26	Z	118,119	59	59	>
56,57	28	27	0	120,121	60	60	\
58,59	29	28	1	122,123	61	61	?
60,61	30	29	2	124,125 126,127	62,63	62	%
62,63	31	30	3				
64,65	32	31	4	Outside range		63	;

Table 7.2: Original video values translated to selected Cyber codes.

ferred to the Cyber readable tape. The problem of scene location was dealt with by visual alignment, while problems of sensor correction were handled using statistical methods (see below).

The conversion program was written and carried out on a Digital PDP 11-40 computer and is listed out in Appendix 2.

7.4 Correction of Original Data

6.4.1 Striping problems

The one significant problem that needs correcting for is the problem of striping. Striping problems occur in the original CCT video data and can be divided into three basic types.

(a) Radiometric striping which is characterized by variations in the film density of imagery which should be uniform. These variations are repeatable and are present in the digital data in the same manner.

This type of striping is due to slight differences in sensitivity among the detectors, and is largely compensated for during processing by NASA.

(b) Sixth Line striping which is characterized by a variation in every sixth scan line of six quantum levels or more from the average quantum level of the other scan lines. It is caused by intermittent hardware problems.

(c) Striping due to intermittent problems which include partial sync loss, full sync loss, track loss or disable, bit slips and demux noise (Anon, 1973b; p.27).

Correction for all striping effects was carried out by a statistical approach involving the calculation of mean radiance values of each detector for each of the four bands. This technique depends on the assumption that the image approximates a random distribution in which

the true means for each of the line sensors should be identical.

A computer program (Appendix 3) was written to list out a frequency table and cumulative frequency table for the strip being investigated. This also prints out the frequency distribution curve for each band as well as that for the normal curve of identical mean and standard deviation (Moroney, 1951; p.109).

The frequency distributions are given in Tables 7.3 a and b, and the actual and normal curves for each of the four bands are presented in Figures 7.3 a,b,c,d. Bands 4,5 and 6 show a marked predominance of certain reflectance levels representing differences in reflectance levels of the image. Band 7 gives a smoother curve with some negative skew.

A computer program was also written to calculate the differences for the six detectors for each band and this is given in Appendix 4. The differences as set out in Table 7.4 are used as the basis for corrections to the original data.

7.4.2 Filtering

The problem of superimposed noise or random variation from the signal has not been found to be an important factor with ERTS data. McCloy (1976) investigated this problem by taking single lines on uniform surfaces such as the ocean. He found that the standard deviation of individual values for each band was in the region of 0.3 to 0.5 of a single level which is considered to be an indication of the noise level. By combining individual pixals into groups for analysis (approximately 10 x 11 in this research), any noise occurrence is likely to be reduced even further.

	BAND4		BAND5	
VALUE	FREQUENCY	TOTAL	FREQUENCY	TOTAL
0/1	5	5	4	4
2	3	8	0	4
3	4	12	0	4
4	0	12	1	5
5	1	13	0	5
6	0	13	5	10
7	0	13	6	16
8	4	17	61	77
9	4	21	102	179
10	1	22	184	363
11	0	22	324	687
12	3	25	310	997
13	58	83	953	1950
14	332	415	2851	4801
15	1217	1632	3080	7881
16	4463	6095	5396	13277
17	23395	29490	16549	29826
18	66025	95515	11588	41414
19	87182	182697	17884	59298
20	154333	337030	29001	88299
21	83365	420395	36003	124302
22	81834	502239	44563	168865
23	112834	615183	46021	214886
24	132482	747665	104104	318990
25	153790	901455	60532	379522
26	99060	1000515	29815	409337
27	114271	1114786	71727	481064
28	162384	1277170	63881	544945
29	98827	1375997	68740	613685
30	72003	1448000	56117	669802
31	106256	1554256	49347	719149
32	70146	1624402	50123	769272
33	66927	1691329	82749	852021
34	32812	1724141	93608	945629
35	35316	1759457	19798	965427
36	37792	1797249	81760	1047187
37	23626	1820875	103958	1151145
38	17944	1838819	59514	1210659
39	14195	1853014	117725	1328384
40	6325	1859339	61987	1390371
41	9840	1869179	100823	1491194
42	5587	1874766	70684	1561878
43	1795	1876561	63363	1625241
44	2242	1878803	87457	1712698
45	475	1879278	42759	1755457
46	773	1880051	35203	1790660
47	336	1880387	31556	1822216
48	403	1880790	16910	1839126
49	193	1880993	17412	1856538
50	187	1881146	9597	1866135
51	30	1881176	8337	1874472
52	63	1881239	4384	1878856
53	52	1881291	2996	1881852
54	31	1881322	1775	1883627
55	6	1881328	1266	1884893
56	23	1881351	558	1885451
57	1	1881352	241	1885692
58	3	1881355	183	1885875
59	1	1881356	66	1885941
60	2	1881358	45	1885986
61	0	1881358	24	1886010
62/63	2	1881360	30	1886040
Outside Range	14040	1895400	9360	1895400

Table 7.3a: Frequency distribution and histogram for bands 4 and 5.

	BAND6		BAND7	
VALUE	FREQUENCY	TOTAL	FREQUENCY	TOTAL
0/1	2	2	2280	2280
2	0	2	4836	7116
3	14	16	3719	10835
4	129	145	4950	15785
5	586	731	7957	23742
6	1315	2046	10211	33953
7	1326	3372	10413	44366
8	1333	5465	12484	56850
9	2133	7564	10212	67062
10	1739	8373	8556	75618
11	1330	10363	8178	83796
12	1604	11967	8987	92783
13	2543	14510	10250	103033
14	2460	16970	10823	113856
15	3062	20032	11086	124942
16	4157	24189	15239	140181
17	5397	29586	15375	155556
18	6353	35939	22574	178130
19	7783	43722	30060	208190
20	10411	54133	40378	248568
21	15358	70191	51355	299923
22	24518	94709	62396	362319
23	36709	131418	64212	426531
24	38060	169478	95548	522079
25	49849	219327	91823	613902
26	63177	282504	97196	711098
27	65240	347744	98736	809834
28	88210	436354	98296	908130
29	81353	517322	97756	1005886
30	113934	631256	98679	1104565
31	73863	705119	94487	1199052
32	59807	764926	124623	1323675
33	104581	869507	129186	1452861
34	97727	967234	125292	1578153
35	38336	1006230	108233	1686386
36	70254	1076494	82899	1769285
37	97204	1173698	57053	1826338
38	40420	1214118	34814	1861152
39	124707	1338825	18642	1879794
40	103460	1442365	9863	1889657
41	74794	1517159	3731	1893388
42	115976	1633135	1395	1894783
43	89013	1722148	453	1895236
44	54679	1776827	123	1895359
45	45311	1822178	26	1895385
46	32436	1854614	10	1895395
47	11874	1866478	1	1895396
48	12497	1878975	3	1895399
49	5398	1884373	1	1895400
50	3453	1887826	0	1895400
51	1811	1889637	0	1895400
52	528	1890165	0	1895400
53	388	1890553	0	1895400
54	121	1890674	0	1895400
55	23	1890697	0	1895400
56	17	1890714	0	1895400
57	5	1890719	0	1895400
58	0	1890719	0	1895400
59	1	1890720	0	1895400
60	0	1890720	0	1895400
61	0	1890720	0	1895400
62/63	0	1890720	0	1895400
Outside Range	4680	1895400	0	1895400

Table 7.3b: Frequency distribution and histogram for bands 6 and 7.

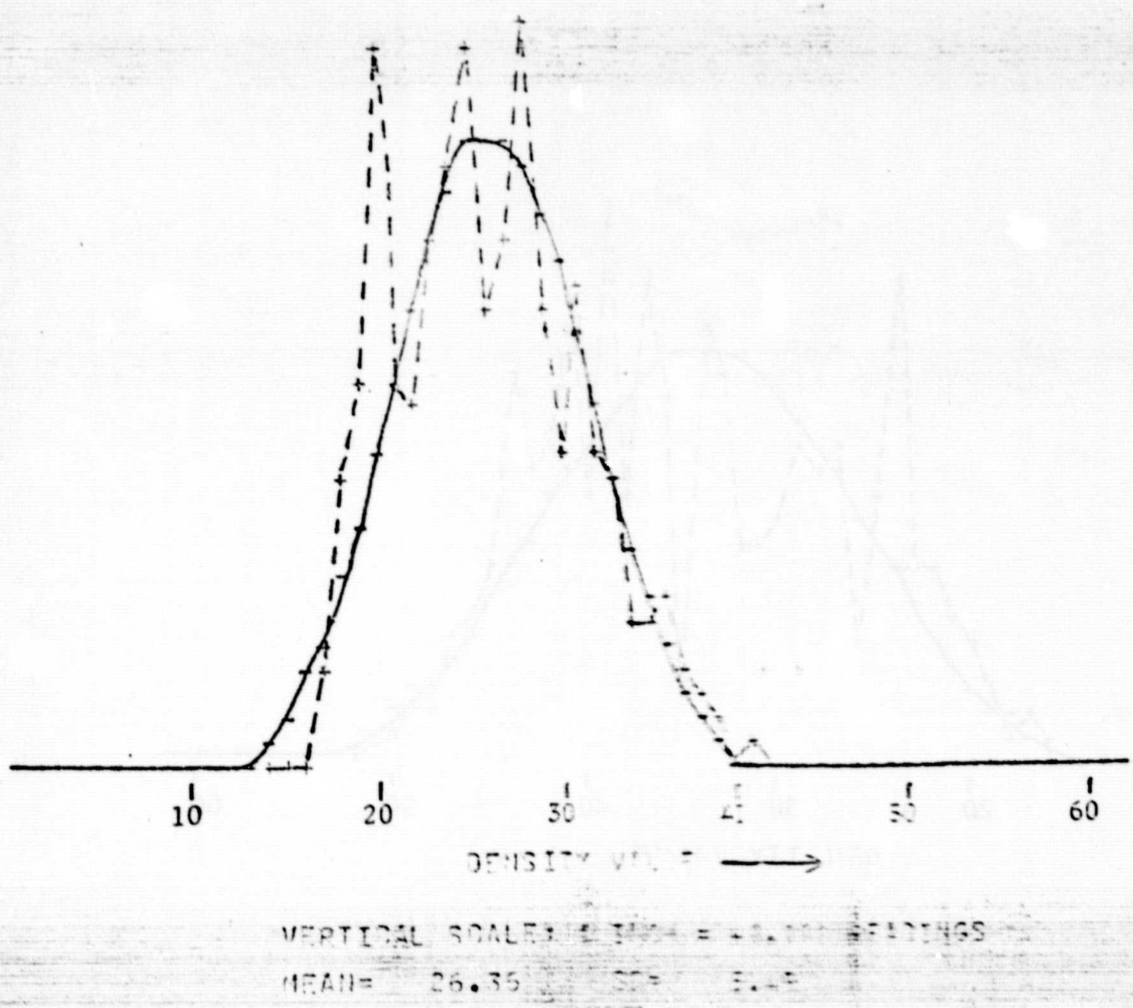
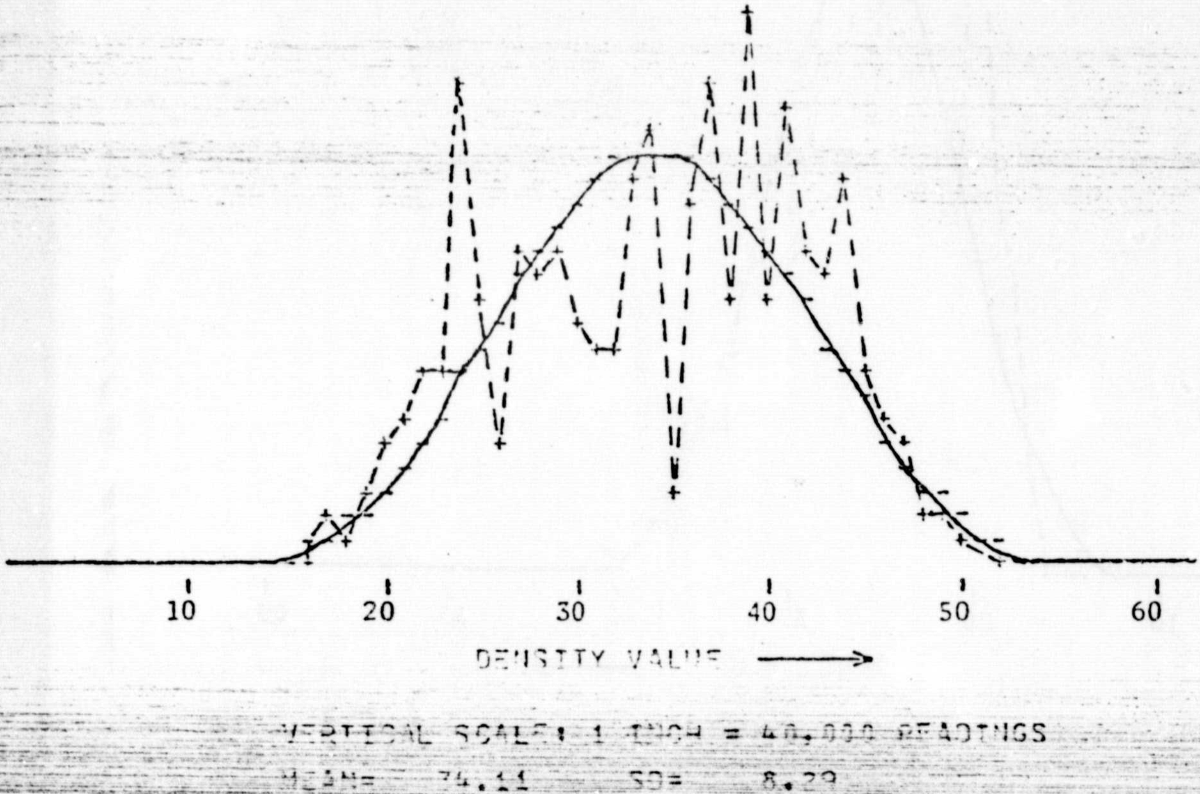


Figure 7.3a: Frequency curve for band [illegible] with normal curve of identical mean and standard deviation.



<u>Figure 7.3b:</u> Frequency curve for band 5 with normal curve of identical mean and standard deviation.

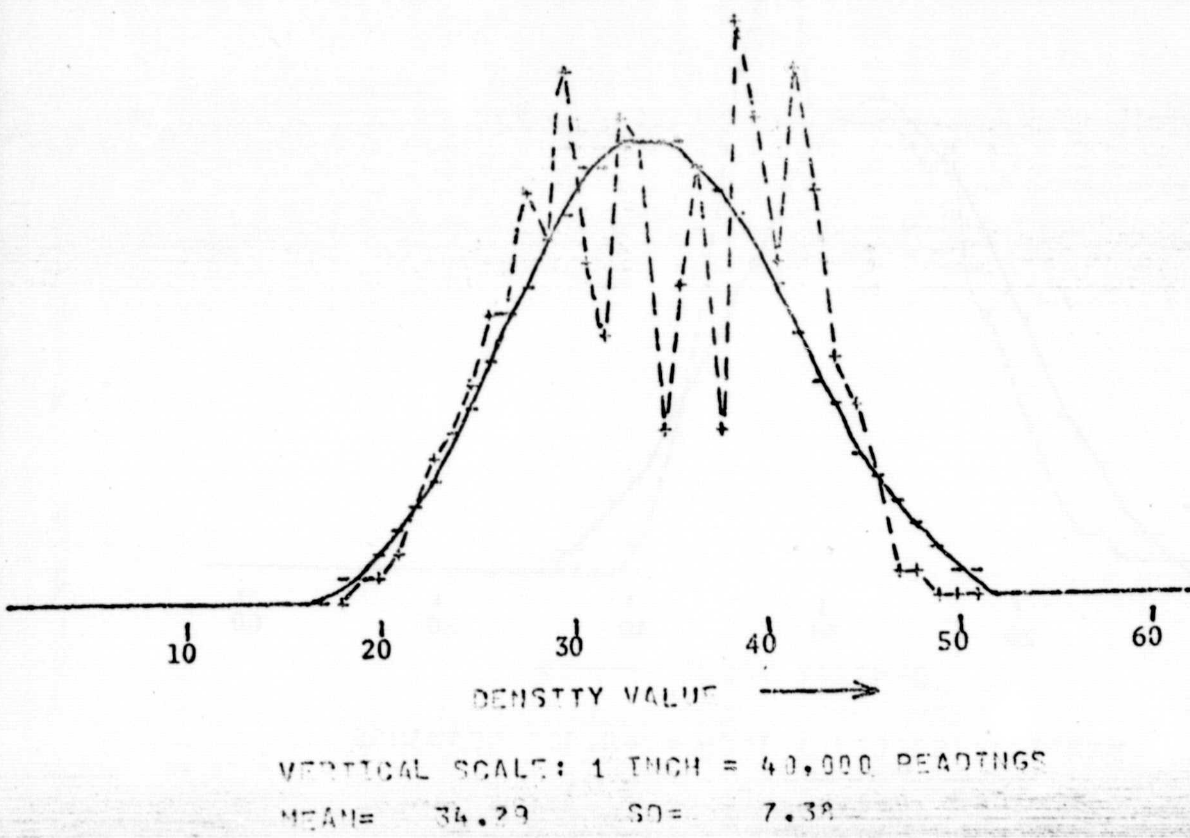


Figure 7.3c: Frequency curve for band 6 with normal curve of identical mean and standard deviation.

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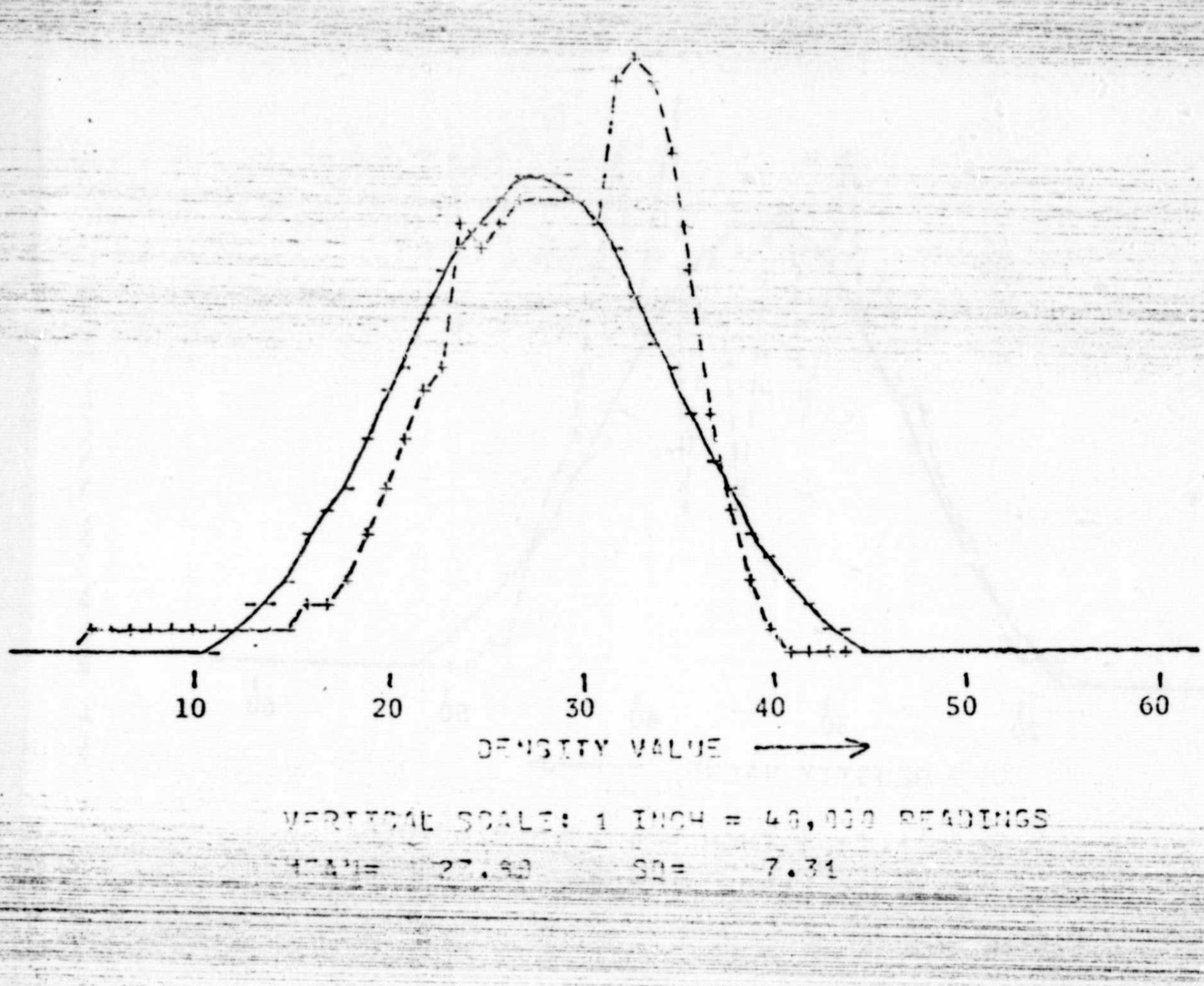

Figure 7.3d: Frequency curve for band 7 with normal curve of identical mean and standard deviation.

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	BAND4	BAND5	BAND6	BAND7
SENSOR MEANS				
LINE 1	26.601	34.318	34.539	27.819
LINE 2	26.565	34.245	34.986	27.703
LINE 3	26.748	34.695	34.882	28.337
LINE 4	27.161	34.607	34.718	27.788
LINE 5	26.811	35.002	35.198	29.773
LINE 6	27.124	34.319	34.637	28.628
AVERAGES	26.835	34.531	34.827	28.341
CORRECTIONS				
LINE 1	.234	.213	.288	.522
LINE 2	.270	.286	-.159	.638
LINE 3	.087	-.164	-.056	.005
LINE 4	-.326	-.076	.108	.553
LINE 5	.024	-.471	-.371	-1.431
LINE 6	-.289	.212	.190	-.286

Table 7.4: Means and corrections for the six detectors for each of the four bands.

7.5 Formatting for Analysis and Display

Since each ERTS scene covers an area of 185 km x 185 km, with individual strips of size 185 x 46.25 km, pictorial representation at the same scale as the terrain classification map (1:250000) corresponds to a size 74 cm x 18.5 cm. For shade prints, in which the hammer distances are 10 characters per inch horizontally and 8 characters per inch vertically, an array of 233 x 73 characters is required. This means that individual video elements or pixals are combined into groups of approximately 10 x 11 for display and processing. A computer program to gather data into such a condensed array and store it on tape for subsequent analysis is listed out in Appendix 5. This routine also incorporates code to apply the sensor corrections as calculated above.

In addition, one further correction is required to account for the spin of the earth. The satellite is orbiting in a near-polar orbit with a declination of approximately 9 degrees. As the satellite traverses a scene, the rotation of the earth introduces an apparent slip between individual lines. Green (1976) has derived a formula for slip correction based on calculations by Kratky (1974) of ERTS orbital geometry. The correction is

$$P = 13.14 \times \sin(\arccos(\sin(L))/\cos(A)))/0.057$$

where P = pixal shift from the first to last scene line

L = latitude (degrees)

A = angle of orbit (9 degrees).

Since the Lake Gregory area is situated at 29°S, the horizontal pixal shift comes to 200.8, equivalent to an angular skew of approximately four degrees.

7.6 Output of Selected Strip

By incorporating these corrections in a program to output shade of character prints, pictorial representation of a particular strip can be generated as required. The program to do this is given in Appendix 6. It includes provision to select intervals to correspond to the gray scale codes, the choice of output as shade print or character output, and the ability to choose one or all four of the various bands.

Shade prints for the four bands for the Lake Gregory scene are given in Plates 7.1, 7.2, 7.3 and 7.4.

These can be compared to the ERTS photographs of the whole scene as given in Plates 3.1, 3.2, 3.3, 3.4. While as expected there is a considerably higher degree of resolution in the photographs, the shade print technique allows a high level of differentiation of the pattern structure.

7.7 Calculation of Principal Components

From the condensed array of 73 x 233 data elements for each of the four bands a 4 x 4 matrix of variances/covariances can be set up in order to calculate all of the principal components. By finding the means and standard deviations of the data, the variances and covariances of the four bands can be determined in both non-standardized and standardized form (the latter forming a matrix of correlation coefficients) and used for calculating the eigenvectors and eigenvalues.

A number of standard routines are available to calculate the eigenvectors/eigenvalues and these can be called from the Cyber mathematical-science library of computer subroutines. Subroutine EIGSYM was selected for this purpose, as this method takes full advantage of the symmetry, reducing the original matrix to tridiagonal form by

Plate 7.1: Shade print of band 4 for strip 1,
Lake Gregory scene.

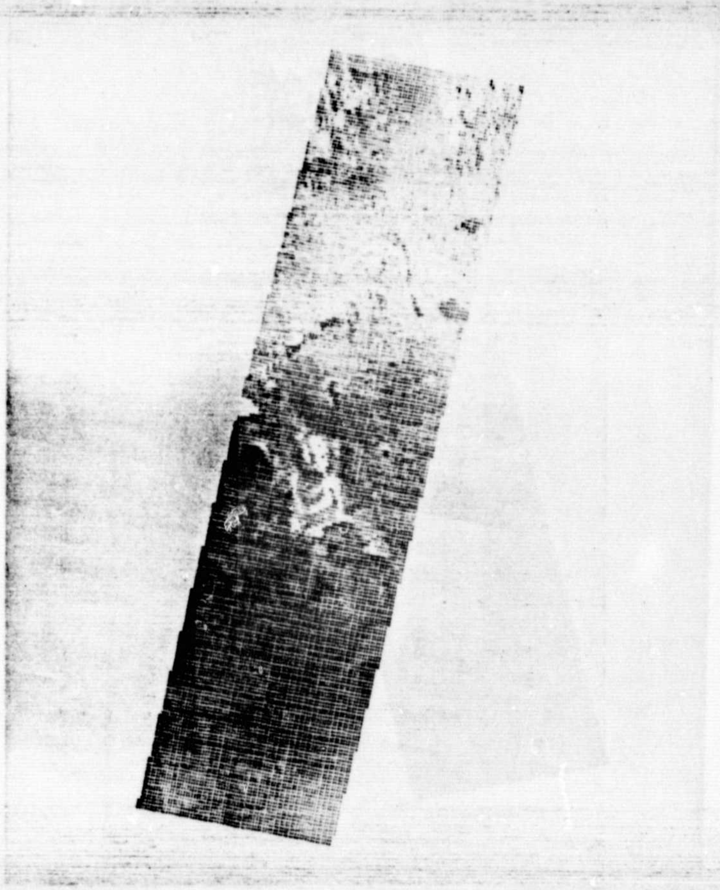

Plate 7.2: Shade print of band 5 for strip 1, Lake Gregory scene.

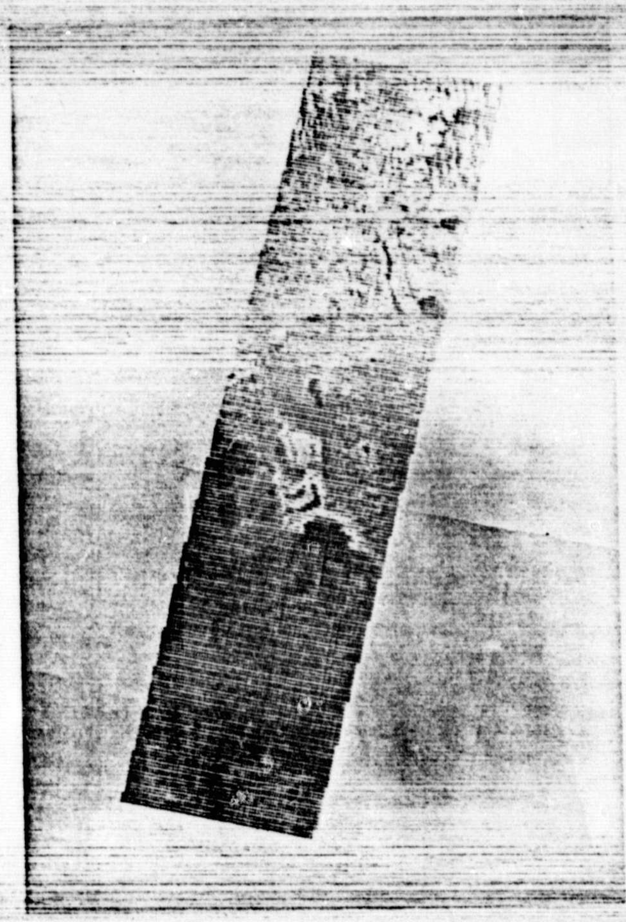

Plate 7.3: Shade print of band 6 for strip 1, Lake Gregory scene.

Plate 7.4: Shade print of band 7 for strip 1, Lake Gregory scene.

...er's method, for easy solution.

The program to set up the variance covariance matrix and to calculate the standardized and non-standardized eigenvectors/eigenvalues is given in Appendix 7. The results are set out in Table 7.5, with the means and standard deviations. For the non-standardized data, inspection of the eigenvalues shows that the first principal component represents 81% of the variance in the original data, while for the standardized data it represents 78% of the original variance.

7.8 Transformation of Original Data onto Principal Components

Having calculated the four principal components the original data set can be transformed onto these axes simply by postmultiplying the data matrix by the respective eigenvectors. The program to calculate the scores of the data elements on the principal axes is given in Appendix 8.

In order to allow visual interpretation of the distribution of values, shade printouts of suitable contour intervals, or character printouts for each of the principal component transformations can then be produced by the program previously given in Appendix 6.

The results for the normalized data transformed onto the first and second principal components for the Lake Gregory area are given in Plates 7.5 and 7.6. To assist in direct comparison with the prints of the original bands, the shade print of the scores on the first principal component is also printed in negative (Plate 7.7).

It can easily be confirmed that the transformed data has variances as indicated by the eigenvalues. (The program as given in Appendix 9 calculated variances for the standardized data of 3.1186 and .7943 for the scores on the first and second principal axes.)

MEANS

26.352	34.116	34.294	27.805

SDS

4.973	7.313	5.987	5.559

NON-STANDARDIZED DATA

VARIANCE/COVARIANCE MATRIX

24.727	31.571	18.827	8.901
31.571	53.486	37.362	24.049
18.827	37.362	35.849	30.263
8.901	24.049	30.263	30.839

EIGENVALUES

117.5933	24.3301	2.8877	.1393

EIGENVECTORS

-.3667	-.6469	-.5334	-.4033
.5482	.3635	-.3052	-.6359
.7516	-.5300	-.0480	.3104
-.0098	.3306	-.7874	.5201

STANDARDIZED DATA

VARIANCE/COVARIANCE MATRIX

1.000	.868	.632	.322
.868	1.000	.865	.592
.632	.865	1.000	.909
.322	.592	.909	1.000

EIGENVALUES

3.1186	.7947	.0816	.0055

EIGENVECTORS

-.4526	-.5363	-.5483	-.4541
.6447	.2841	-.2642	-.6587
.6160	-.6323	-.1432	.3658
-.0123	.4066	-.7800	.4766

Table 7.5: Variance/covariance matrices, eigenvalues and eigenvectors of Lake Gregory area.

Plate 7.5: Shade print of the standardized band data transformed onto the first principal component for strip 1, Lake Gregory scene.

Plate 7.6: Shade print of the standardized band data transformed onto the second principal component for strip 1, Lake Gregory scene.

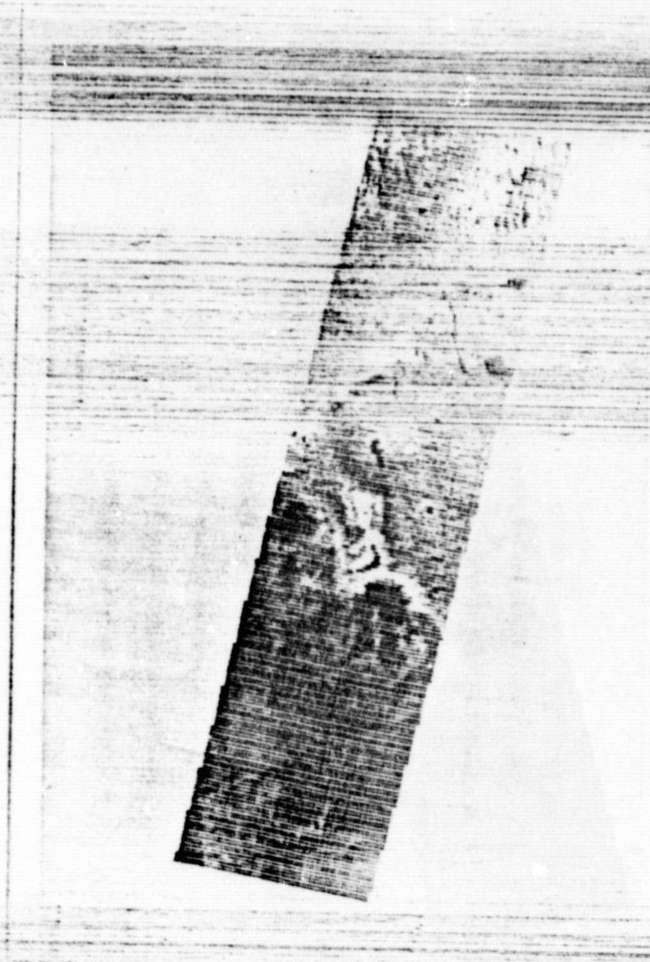

Plate 7.7: Shade print of the standardized band data transformed onto the first principal component for strip 1, Lake Gregory scene, shown negative to figure 7.5.

To allow more detailed investigation for the standardized data a program was written (Appendix 10) to set out a frequency plot of scores on the first and second principal axes (Figures 7.4 a,b). These show a bimodal distribution of scores on the first principal component, and a lognormal type distribution along the second principal component.

Alternatively the frequency of occurrence can be printed as an array in two dimensions (Figure 7.5). This also reveals the double clustered nature of the data along the first principal component and the broad extension of scores along the second principal component.

These plots allow a straightforward classification of the map area to be carried out simply by selecting breaks in the continuum of scores on each of the axes. Such a threefold classification, based on the two nodes of the first principal component and the tail of the second principal component, results in a subdivision of the area as displayed pictorially in Plate 7.8.

By approaching classification through the delineation of natural clusters (i.e. areas of higher concentrations) the structure of the scores can be investigated by determining residuals. A computer program (Appendix 11) was written to calculate the residual at each point, by subtracting from the actually occurring concentrations the average of values calculated on the grid of surrounding points. Residuals calculated on this basis for 9 x 9 grids are set out in Figure 7.6.

These also highlight the excess concentration of values around two nodes along the first principal axis but do not reveal any other significant groupings.

7.9 Cluster Analysis of the Data

Cluster analysis was carried out using program POLYDIV

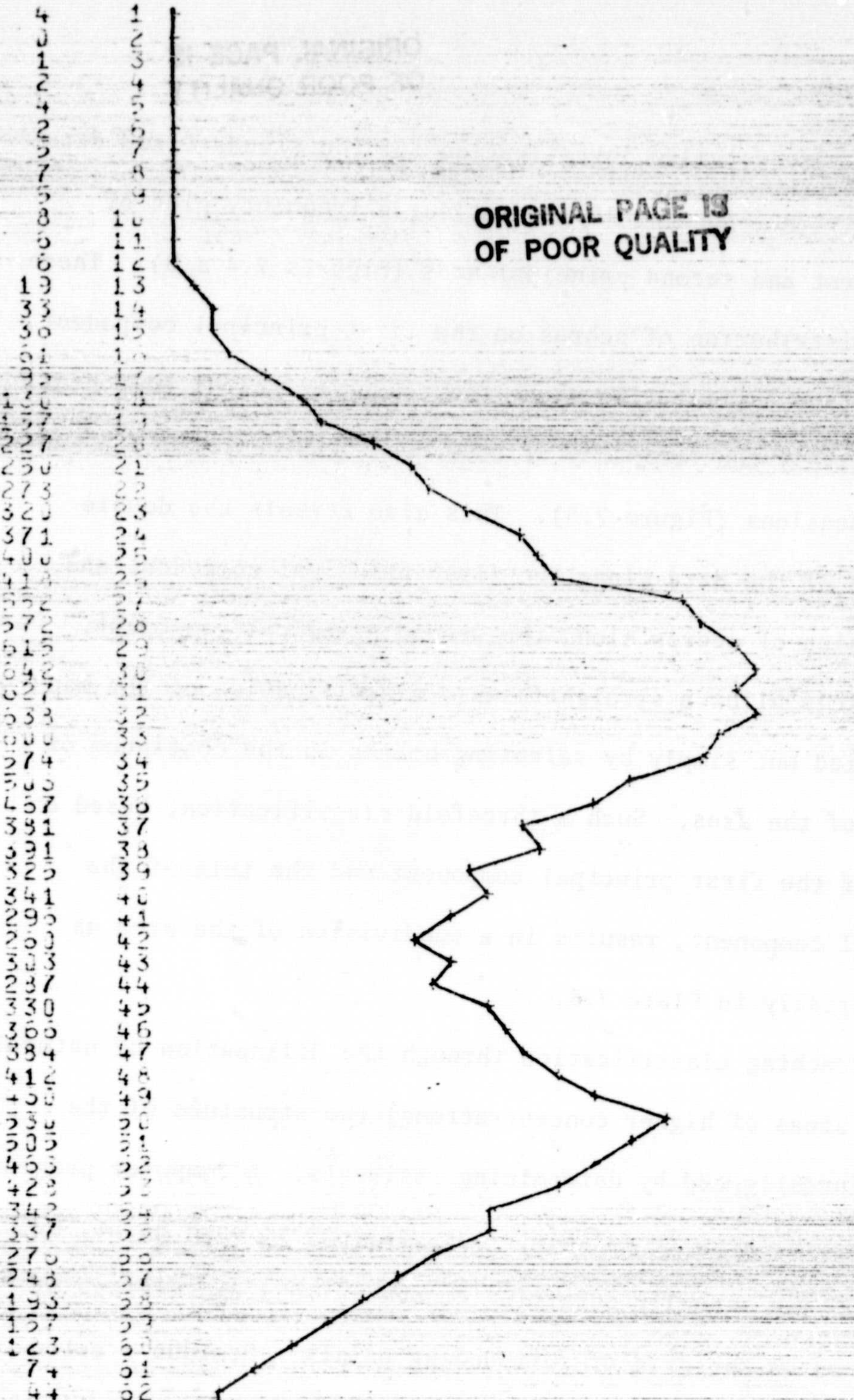

Figure 7.4a: Frequency distribution of scores on the first principal component.

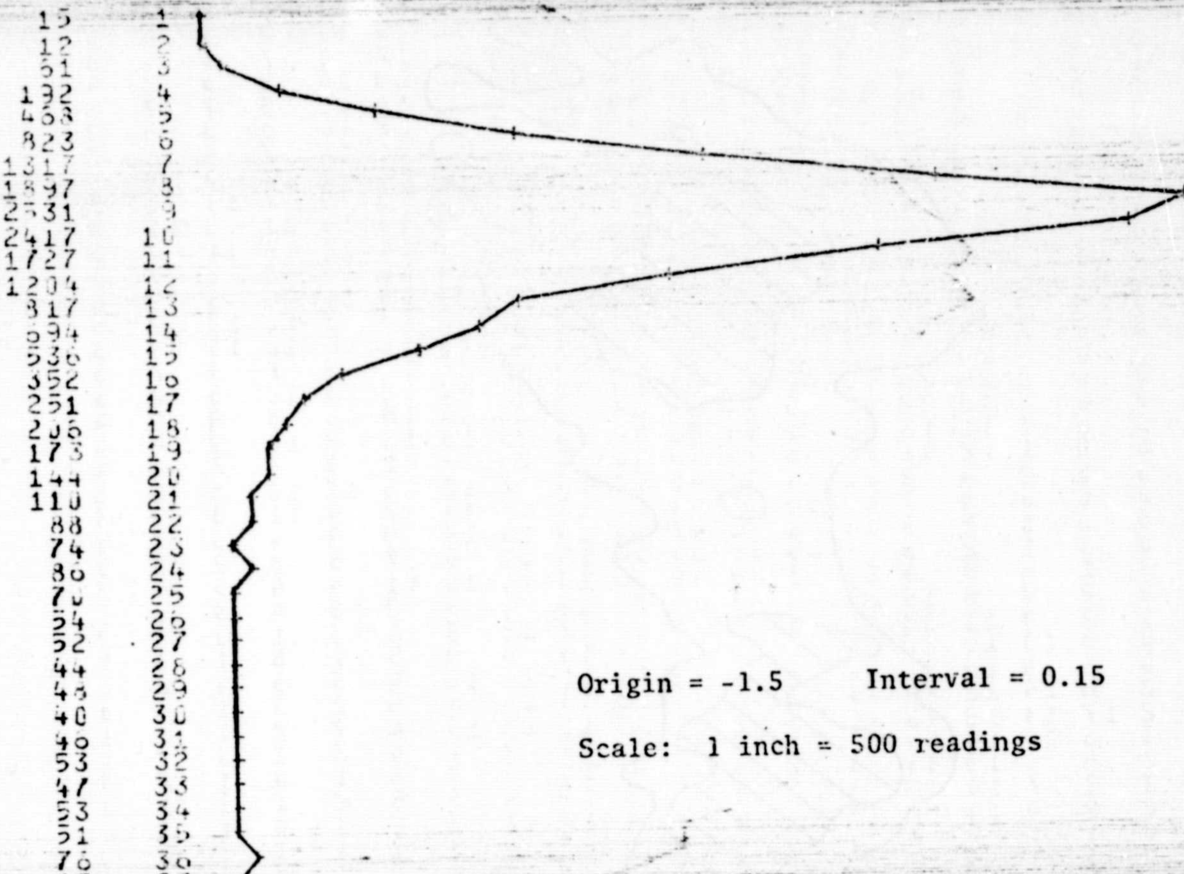

Figure 7.4b: Frequency distribution of scores on the second principal component.

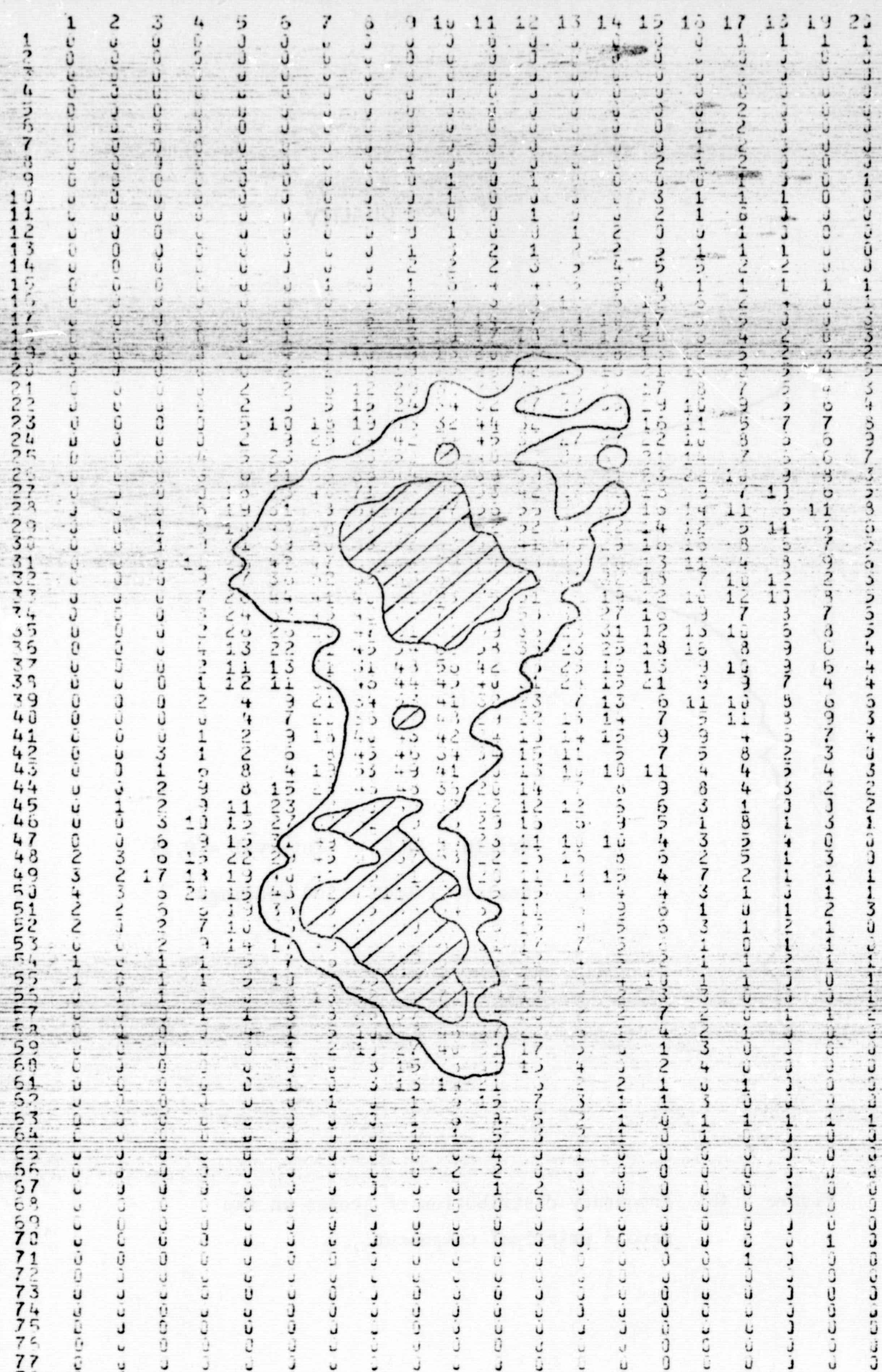

Figure 7.5: Two dimensional frequency distribution of scores on first and second principal components.

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	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	1	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	2	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	4	2	2	0	1	1	1	0	0	0	0	2	0	4	0	0	0	0	0	0
22	2	4	2	1	1	0	0	0	0	0	0	1	4	1	0	0	0	0	0	0
23	2	2	0	0	2	0	0	0	1	0	0	2	0	1	0	0	0	0	0	1
24	2	4	0	0	2	0	0	0	0	0	1	1	3	0	0	0	0	0	0	0
25	2	2	2	1	2	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0
26	3	2	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
27	3	4	1	4	5	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0
28	2	2	2	2	2	1	0	2	0	0	2	0	1	0	0	0	0	0	0	1
29	4	3	1	0	4	1	2	1	0	1	1	1	1	0	0	0	0	0	0	1
30	5	3	1	1	2	2	2	1	2	0	2	1	0	0	0	0	0	0	0	0
31	5	6	3	4	1	2	1	2	2	2	0	0	1	2	1	0	0	0	0	0
32	6	6	1	2	3	3	1	1	4	1	0	0	2	0	1	0	0	0	0	0
33	2	3	1	2	7	1	2	4	3	0	2	0	2	1	0	1	0	0	0	0
34	2	2	5	1	2	4	2	1	4	0	2	0	2	1	1	0	0	0	0	1
35	5	5	4	3	6	1	1	1	3	1	3	3	3	2	0	1	0	0	0	0
36	3	1	5	7	4	4	3	1	1	0	0	3	1	1	0	1	0	0	1	0
37	3	3	3	4	1	2	1	2	0	1	3	2	0	0	1	0	0	0	0	1
38	4	1	5	3	4	0	2	4	2	0	2	0	0	2	1	3	0	0	1	1
39	6	3	3	2	1	0	3	2	2	5	1	2	2	1	2	2	0	0	0	1
40	3	1	4	4	5	2	2	1	0	5	0	1	2	4	1	0	0	0	0	0
41	3	2	3	5	0	2	1	0	3	1	2	0	1	1	3	1	3	0	0	0
42	2	0	3	4	2	1	1	2	2	2	0	2	0	1	0	1	1	1	0	0
43	1	2	2	2	2	1	4	2	3	2	2	1	0	0	1	1	0	0	2	0
44	3	1	1	1	0	1	2	1	1	2	1	0	0	1	1	0	0	0	0	2
45	5	1	1	7	2	2	1	1	1	1	1	0	1	0	0	0	0	0	1	1
46	2	1	3	3	0	0	0	1	0	1	1	2	2	1	1	2	0	0	1	2
47	2	1	1	2	0	1	2	2	0	0	3	0	0	1	2	4	3	0	0	0
48	3	2	1	3	0	3	0	1	1	3	3	0	1	3	0	5	2	0	0	0
49	0	1	0	1	2	1	2	0	2	0	3	1	1	1	3	3	3	1	1	2
50	1	1	1	3	1	1	0	0	2	2	1	4	0	4	3	6	2	3	1	0
51	1	1	1	0	0	2	1	1	1	0	0	1	4	5	2	11	10	1	2	1
52	0	0	2	1	0	1	1	1	0	0	1	1	1	3	0	4	8	2	1	1
53	0	0	0	1	1	0	1	4	0	0	1	0	1	1	2	6	8	5	2	0
54	0	3	0	0	0	0	1	0	0	0	1	2	1	1	2	3	5	2	2	0
55	0	1	2	1	0	1	1	0	1	1	1	0	1	1	2	3	3	5	2	0
56	0	1	0	0	1	1	1	0	0	1	0	0	1	2	2	1	3	5	4	0
57	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	1	6	7	5	0
58	0	0	1	1	0	1	1	0	0	0	2	0	1	0	3	1	2	5	2	3
59	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	1	5	7	2
60	0	0	0	0	2	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0
61	0	0	0	0	0	1	0	0	1	1	1	4	0	0	0	2	0	0	0	0
62	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	1
63	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0
64	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0	0	2
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
70	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0
73	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1
74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	0	0	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0
77	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0
79	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
80	0	0	0	1	0	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0

Figure 7.5 cont: Two dimensional frequency distribution of scores on first and second principal components.

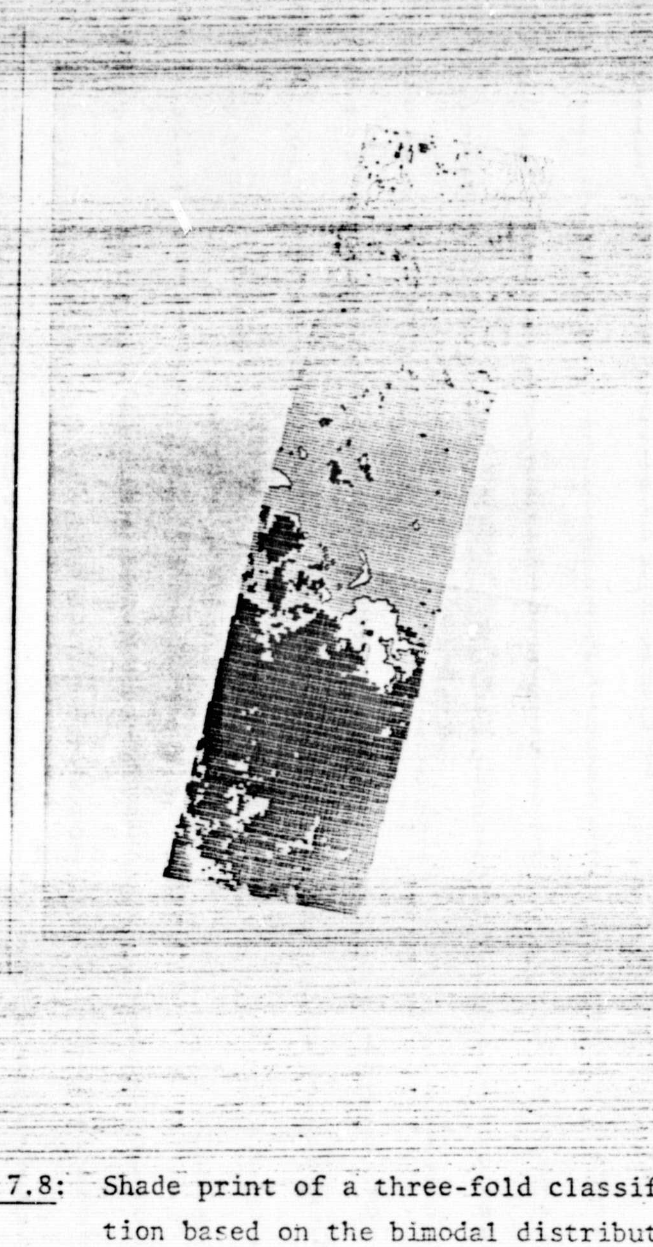

Plate 7.8: Shade print of a three-fold classification based on the bimodal distribution on the first principal component and the lognormal distribution on the second principal component.

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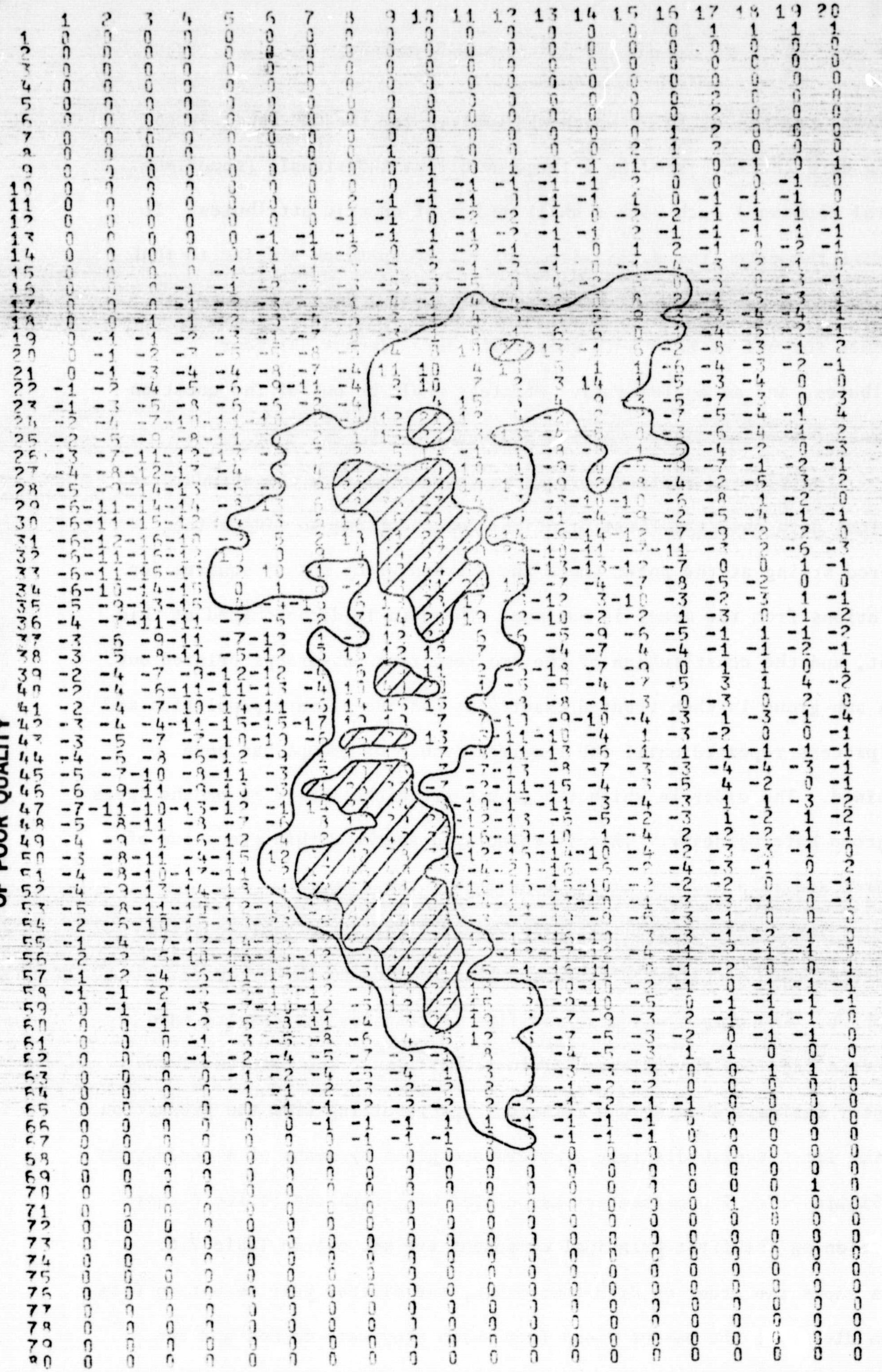

Figure 7.6: Residual values of principal component scores

(Williams and Lance, 1975) which was written for the CDC Cyber 76 to handle data characterized by a large number of individuals (sometimes several thousand) each with a small number of numeric attributes. It analyses the data from a divisive, polythetic approach similar to that used in the program AXOM (Lambert et al., 1973). Such a program is suitable for use on ERTS data where each data element has four attributes, and an agglomerative strategy would be out of the question because of the enormous computing overhead.

The cluster analysis procedure is to transform the standardized original data onto the first principal component and to divide the ordered string at the point where the between group sum of squares (or deviations from the mean) is maximum. The data is dichotomized at this point, and the constitution of the two resulting sub-groups printed out. Each sub-group is then treated exactly as was the primary population and the process repeated until the required number of groups has been obtained. The order in which the groups are dichotomized is on the basis of group heterogeneity. This is calculated as the within group sum of squares and is a measure of the cohesian of the group.

The program which initially required card input was modified to accept data on magnetic tape, and also adapted to the Cyber 72 computer. The output was also modified to transfer the results onto magnetic tape for analysis and pictorial display. The results of the cluster analysis showing the relationships resulting from the production of the first twelve discrete clusters are given by means of a dendrogram in Figure 7.7. The parameters associated with each successive dichotomization on the first principal component are set out in Table 7.6. This shows the order of dichotomization, the cluster pair resulting from each division, the parent group from which they were formed and the

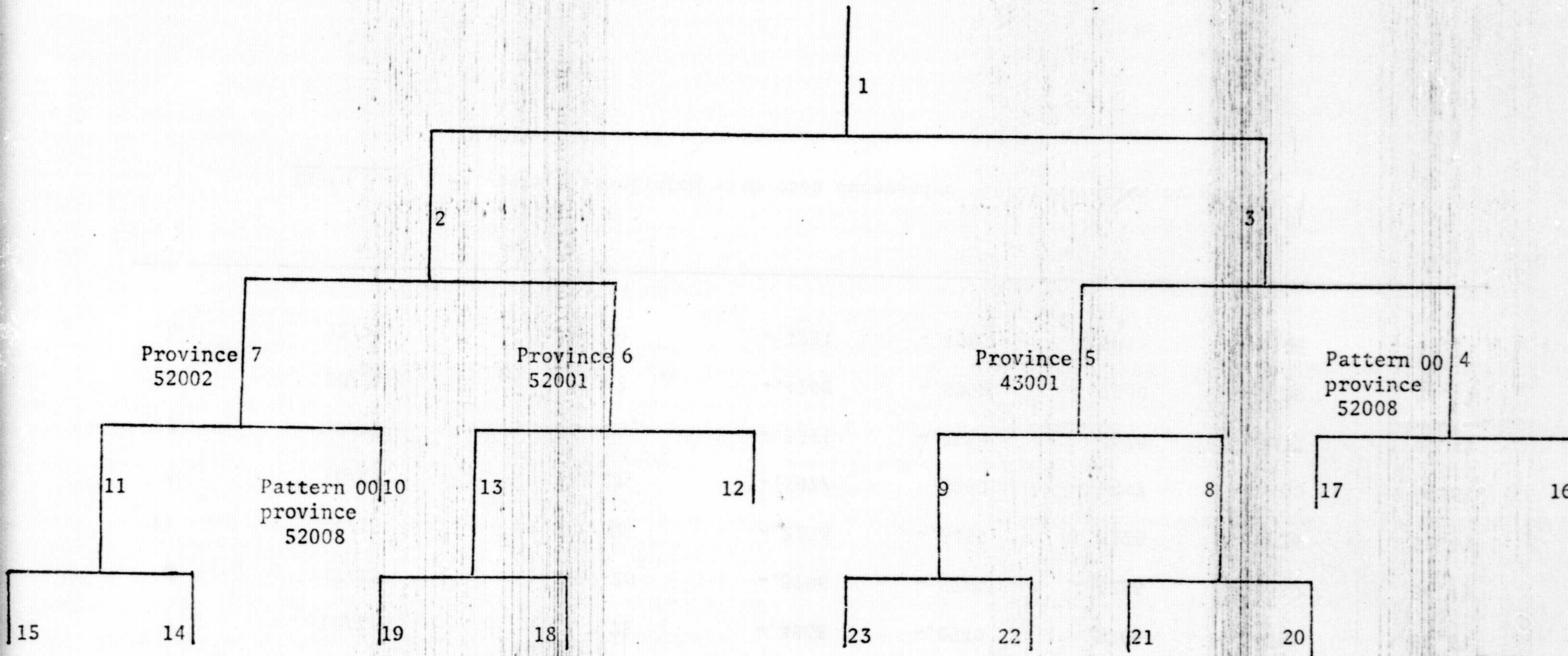

Figure 7.7: Dendrogram Showing Relationships of First 12 Discrete Clusters Produced by Program Polydiv.

Parent	Cluster pair	Heterogeneity	Coefficients Band 4	Band 5	Band 6	Band 7	Variance
1	2/3	19.54/19.93	-.4566	-.5345	-.5466	-.4551	79.1%
3	4/5	2.55/7.81	-.5895	-.4491	.3397	.5792	53.5%
2	6/7	5.19/7.15	-.3622	-.5618	-.5943	-.4472	65.1%
5	8/9	1.88/1.83	-.4675	-.5151	-.5776	-.4649	78.3%
7	10/11	1.58/2.78	-.4868	-.0549	.5706	.6591	52.8%
6	12/13	1.49/2.20	-.3796	-.5766	-.6253	-.3639	54.4%
11	14/15	1.31/.62	-.2153	-.5485	-.6326	-.5026	59.4%
4	16/17	1.47/.27	-.3972	-.5269	-.6047	-.4460	60.6%
13	18/19	.57/.84	-.5344	-.3554	.4678	.6077	60.4%
8	20/21	.59/.62	-.4790	-.5992	-.5909	-.2499	48.5%
9	22/23	.64/.39	-.4251	-.4905	-.5814	-.4905	64.1%

Table 7.6: Parameters associated with each successive dichotomization by program POLYDIV

heterogeneity values associated with the resulting clusters. The coefficients of the first principal component used for cluster division and the percentage of variance it represents are also given.

By using the character array option of the pictorial output program and colouring the areas according to their classification code the spatial distribution of the first four and the first seven discrete clusters respectively can be shown as in Plates 7.9 and 7.10.

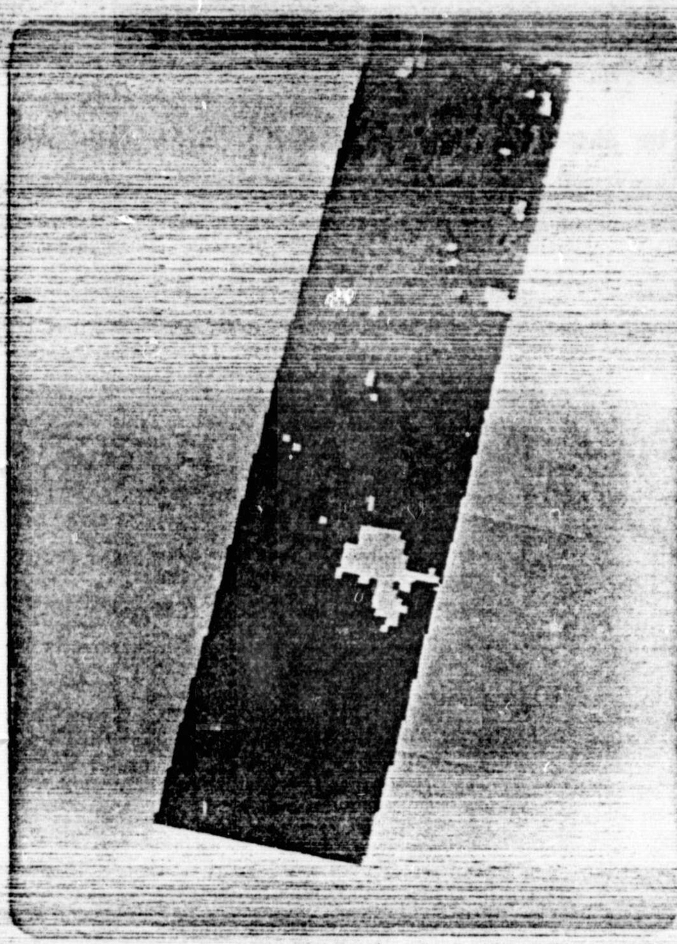

Plate 7.9: Distribution of POLYDIV clusters 1 to 4
for strip 1, Lake Gregory scene.

Plate 7.10: Distribution of POLYDIV clusters 1 to 7 for strip 1, Lake Gregory scene.

CHAPTER 8: DISCUSSION OF THE RESULTS

8.1 Transformations onto Principal Components

The results of the calculation of the principal components (Table 7.5) show that for the non standardized data set the first principal component accounts for 81 per cent of the variance in the original data while the second accounts for over 16 per cent. When the original data is standardized the resulting first principal component accounts for over 78 per cent of the original variance and the second principal component almost 20 per cent of the variance. In both cases the first two principal components account for almost 98 per cent of the variance in the original data.

Thus the information contained in the four spectral bands can be interpreted by analysis in two dimensions with negligible loss of information. Indeed most of the detail is contained in the first principal component which allows considerable analysis from a single dimension only.

The results also show that for this investigation the question of whether or not the original data should be normalized is really unimportant, since both the form and magnitude of the transformations are almost identical. Therefore the decision to carry the analysis through on the standardized data set was taken on the basis that the cluster analysis program POLYDIV operated on standardized data, and this allowed more ready comparison between the methods.

Inspection of the eigenvectors involved in the transformations shows that the first principal component score is created as the negative sum of approximately one half of each individual band value. Thus the relationships of the string of scores on the first principal

component are the same as those produced by simple addition of the respective band values. On the other hand the second principal component is created by the application of negative coefficients to bands 6 and 7 and positive coefficients to bands 4 and 5. This implies that there are certain underlying features in the original data which are represented in terms of higher reflective values in band 4, moderately high and low values respectively in bands 5 and 6, and areas of lower reflectance in band 7.

While it could be argued that a plot of scores similar to that measured on the first principal component could be arrived at intuitively, trial and error methods would be unlikely to highlight the transformation involved in determining the second principal component, and certainly would not allow confident interpretation and deductions as to the relative importance of such plots.

8.2 Classification by Cluster Analysis

Classification by program POLYDIV to the level of twelve discrete clusters was carried out in order to investigate the underlying composition of the original data set. Such an extensive grouping of the data goes at least to the point where resolution and interpretation in terms of meaningful terrain features is practicable. However the parameters associated with this level of clustering highlight certain relationships.

For example Table 7.6 shows that nine of the twelve first principal components (which the cluster analysis uses as the basis for dichotomization) are defined by eigenvectors all closely similar in form to the first principal component of the principal component analysis (Table 7.5). In turn the eigenvectors defining the other three are all

closely similar in form to the second principal component of the PCA. This confirms the fact that the relationships between all the original elements are almost totally revealed by transformations onto two axes.

The cluster dendrogram (Figure 7.7) also shows that classification along what in the PCA is the second principal component occurs as three separate steps in the cluster analysis procedure resulting from divisions of three distinct parent groups, viz. 3, 7 and 13.

8.3 Interpretation of the Analyses

8.3.1 Original data

On the shade prints for each of the bands (Plates 7.1, 7.2, 7.3, 7.4), the dark areas indicate regions of low reflectivity whereas the lighter areas indicate more reflective surfaces. A table has been drawn up (Table 8.1) which relates the reflective characteristics of each image to the terrain classifications of Grant (1970 a,b,c).

(a) The feature highlighted by band 4 is province 52001 which can be identified within the area of highest reflectance values. Also included within these higher reflectance values is terrain pattern 00 of province 52008. Provinces 52002 and 43001 in the south are indistinguishable within the areas of lower reflectance.

(b) Band 5 shows a less clearly defined pattern structure. Province 52001, which was well presented in band 4, is here poorly defined within province 52002. To the south province 43001 is broadly distinguishable as an area of lower reflectance, while province 52008 corresponds to some areas of high, neutral and low reflectance.

(c) In band 6 quite a good level of differentiation between all four provinces in the region is attained. As in band 5 province 52001 can be identified with the region of high reflectance values and

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Classification	Band 4	Band 5	Band 6	Band 7	First Component	Second Component
Province 43001 (Rolling Downs Group)	Considerably lower reflectance than province 52001; generally lower than province 52002 and pattern 00 of province 52008; similar appearance to patterns 01,06 of province 52008	Lower reflectance than province 52001; lower generally than 52002; similar in appearance to pattern 00 of province 52008	Lower reflectance than province 52001 and 52002; slightly higher reflectance than province 52008	Slightly lower reflectance than province 52001 and province 52002; higher reflectance than province 52008	Characteristically higher scores than province 52001 and 52002; lower scores than province 52008	Low scores
Terrain Patterns: 01/2 01/3 03/1 and 03/2	Not differentiated	Areas of slightly lower reflectance within province	Lowest reflectance within province; indistinguishable from patterns 01 and 06 of province 52008	Poorly differentiated	Areas of slightly higher scores	Not differentiated
01/11 and 01/16	Not differentiated	Areas of slightly higher reflectance within province	Areas of higher reflectance within province	Poorly differentiated	Areas of lowest scores	Not differentiated
Province 52001 (Alluvium) Terrain pattern 11/3	Characteristically highest reflectance values. Clearly distinguishable from province 43001 and 52002; poorly differentiated from pattern 00 province 52008	Associated with highest reflectance values	Associated with highest reflectance values	Poorly distinguishable as areas of highest reflectance	Characteristically areas of lowest scores. Clearly distinguishable from other provinces	Low scores

Classification	Band 4	Band 5	Band 6	Band 7	First Component	Second Component
Province 52002 (Aeolian sand) Terrain pattern 11	Slightly higher reflectance than province 43001; lower reflectance than province 52001	Slightly higher reflectance than province 43001; lower reflectance than province 52001; undifferentiated from province 52008	Higher reflectance than province 43001 and province 52008; lower values than province 52001	Slightly higher reflectance than province 43001; higher than province 52008; indistinguishable from province 52001	Characteristically higher scores than province 52001 but lower than province 43001 and province 52008	Low scores
Province 52008 (More recent alluvium, colluvium)	Poorly defined; can be seen as areas of high, neutral or low reflectance	No general appearance; can be seen as areas of high, neutral or low reflectance	Distinguished as lowest reflectance areas; within province 43001 merges into province	Distinguished as lowest reflectance areas	Associated with areas of highest scores	Characteristic highest scores for pattern 00 only; low scores for patterns 01,06
Terrain patterns 00	Not differentiated	Not differentiated	Not differentiated	Not differentiated	Slightly lower scores	Characteristic high scores
01 and 06	Not differentiated	Not differentiated	Not differentiated	Not differentiated	Slightly higher scores	Low scores

Table 8.1: Details of terrain pattern representation in terms of the original band data and scores on the first and second principal components.

province 52002 is distinguishable as an area higher in reflectance than province 43001. Province 52008 is represented by the areas of lowest reflectance.

(d) In band 7, province 52008 can be identified most clearly as regions of lowest reflectance. The differentiation of provinces 52002 and 43001 remain as good as for band 6, but separation of province 52001 from province 52002 is difficult.

Thus all bands contain considerable information on the provinces in the area, but the major problem is to decide between the bands what are the significant pattern structures. Correlations with the terrain pattern map (above) show that careful selection of boundaries can result in a close demarcation of individual provinces, but a correct selection depends on such a priori knowledge of the terrain. Here province 52001 can be marked off on band 4 and the areas of low reflectivity constituting province 52008 marked off from band 7. The general line of demarcation between province 43001 and province 52002 can be selected from bands 6 or 7.

But what is needed is a method of collating the details of all four bands so the choice of meaningful boundaries is simplified. This is the value of principal components analysis, in which the greatest amount of the information in the four bands can be reduced to a single set of data and virtually all for solution in two dimensions.

8.3.2 Principal Components analysis

The results produced by transformation onto the first and second principal components are shown in Plates 7.5 and 7.6 with dark areas representing low scores and light areas high scores. (For ease of comparison with the four original bands the principal component is

given in negative in Plate 7.7.)

By comparing these results to the original bands it is clear that there has been enhancement of the original data and increase in resolution between what are known to be important features of the area. The results are set out in tabular form in Table 8.1.

On the first principal component province 52001 shows up as a distinct feature of low scores, while the boundary between province 43001 and province 52002 is well marked as a difference in levels. As in bands 6 and 7 there is reasonable differentiation of the structure within province 43001.

However on the second principal component most strikingly defined are the areas of very high scores. These correlate closely on the terrain pattern map and aerial photographs to pattern 00 of province 52008 which represents the lake and playa areas containing water.

Thus the problem of boundary selection has been considerably reduced from the original 4-band ERTS set. First, the areas defined by high scores on the second principal component could be marked off. Then the first principal component could be subdivided on the basis of its pattern structure, with four groups being selected corresponding well to the provinces already described.

However as an alternative approach, rather than interpret the data visually, the area could be subdivided on the basis of the cumulative frequency plots of scores on the first two principal components. These reveal sufficient detail on the structure of the data set to encourage broad classification, and show the scores being grouped into three underlying natural elements identified separately by the two nodes in the first principal component and the extended set of values along

the second principal component (Figures 7.4 a,b).

In Plate 7.8 the lower value node on the first principal component (represented by the intermediate shading) contains provinces 52001 and 52002, while the node of higher scores (represented by the darker shading) corresponds in extent to province 43001. The high scores on the second principal component (unshaded areas) correspond quite closely to pattern 00 of province 52008 (the water filled lakes and playas).

These results imply underlying associations within the terrain which are not intuitively obvious from classification by 'landscape' analyses. For example, one suggestion is that province 52001 and 52002 are genetically related, being as they are, both contained within a single node but distinguishable as the lower and higher scores respectively. Similarly of interest is the association of terrain patterns 01 and 06 of province 52008 with province 43001, which are once again separated out on the basis of higher and lower scores respectively.

Thus while province 52001 and pattern 06 of province 52008 both consist of drainage features, stream channels, flood plain levels, etc. they are placed the most distant on the spectrum of principal component scores.

On the second principal component the differentiation is between the tail of high scores representing pattern 00 of province 52008 and the rest of the terrain types contained within the single node. This can be interpreted as revealing a basic distinction between the water filled lakes and playas and the consolidated and unconsolidated landforms of earthern materials.

8.3.3 Cluster analysis

On Plate 7.9 showing the first four discrete classifications as determined by program POLYDIV, the colour code is

cluster 4 = white

cluster 5 = black

cluster 6 = blue

cluster 7 = orange

while on Plate 7.10 showing the first seven discrete clusters, the colour code is

cluster 4 = white

cluster 8 = yellow

cluster 9 = black

cluster 10 = dark green

cluster 11 = orange

cluster 12 = red

cluster 13 = blue

(where the cluster numbers refer to those of the dendrogram, Figure 7.7).

Looking at the presentation of these results and those produced by PCA (Plates 7.5,7.6) there is excellent correlation between the clusters and the pattern features of the shade prints.

At the first level of resolution cluster 4 corresponds to the detail given in the second principal component, while clusters 5, 6 and 7 can be identified as the areas of highest, lowest and average reflectance values respectively on the first principal component. At the next level of differentiation a direct comparison can be made between clusters 8 to 13 and the detailed features produced by the PCA.

Alternatively, by comparing the results directly with the terrain

pattern map, cluster 4 is seen as comprising part of pattern 00 of province 52008, cluster 5 corresponds to province 43001, and clusters 6 and 7 broadly represent provinces 52001 and 52002 respectively. At the next level of differentiation cluster 12 can be identified closely with province 52001, clusters 8 and 9 correspond to the broad terrain pattern features of the Rolling Downs Group and clusters 11 and 13 give a subdivision of province 52002 in terms of association with the floodplain of Cooper's Creek.

However the interpretation of cluster 10 is more informative. Cluster 10 is produced by a transformation along an axis similar in form to that defined by the second principal component of the PCA and as in that analysis this also results in the separation of water saturated areas from other terrain. Here this represents a further part of pattern 00 of province 52008 and highlights an association between clusters 4 and 10.

Thus cluster analysis gives a different view of the relationships of the terrain. Rather than producing the intrinsic three-fold classification of the PCA, cluster analysis, by necessitating successive dichotomization of the data, results in the major part of the water-zone classification being initially included with the Rolling Downs Group, with another section being separated out at a lower level from the unconsolidated sands and alluvium.

CHAPTER 9: CONCLUSIONS

The aim of the research was to carry out an analysis of ERTS 4-band multispectral data, particularly with regard to its use as a means of evaluating and classifying terrain for engineering purposes. The study was concerned with broad scale application in an arid region of terrain located in the north-east of South Australia. The investigation was carried out on a digital computer by the application of multivariate techniques, and utilized a straightforward method of presentation by means of shade or character prints.

The results showed that representation of the original data for each of the four bands allowed a certain degree of terrain interpretation. However variations in appearance of sites within and between bands, without additional criteria to decide which representation should be preferred, created difficulties for classification.

The value of the multivariate techniques was that by reducing the dimensionality of the problem while at the same time maintaining and consolidating all the information of the original data set, selection of significant divisions in the pattern structure could be simplified.

Investigation of the video data groups produced by principal components analysis and cluster analysis techniques showed that effective correlations with classifications of terrain produced by conventional methods could be carried out. The analyses also highlighted underlying relationships between the various elements.

The advantage of the cluster analysis approach is that it automatically provides a selection of classifications for field investigation and verification rather than requiring visual interpretation as for PCA. However PCA provides a more detailed understanding of the underlying

structure of the data, allowing an assessment as to what level classification is likely to prove meaningful.

For broad scale studies the techniques evolved in this research could readily be applied in practice. First for a selected ERTS scene, a basic mozaic of patterns could be established to a selected level of video differentiation. Then a sampling program based on the different representations could follow to determine their significance in terms of terrain parameters. This could be based on a number of sample sites for each group, and these could be selected on the basis of accessibility or the availability of additional contributory data. Such a study could be by means of a qualitative 'landscape' investigation or in terms of quantitative field analyses. By integrating results of this sampling program with the originally selected patterns, validated classification maps could be produced.

The significant advantage of using digital ERTS data is that for large tracts of land covered by a single scene (185 x 185 km) an initial mozaic of patterns can be obtained in only a few hours. In addition such an approach is readily applied to remote or difficult areas, where facilities such as aerial photographs and roads, necessary for conventional studies, are lacking.

For these reasons the methods developed in this research could contribute significantly to practical studies, particularly for evaluation of terrain in remote or underdeveloped areas of the world.

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Appendix 1

```
      SUBROUTINE MAP1(ICHAR,IFLAG)
C
C     THIS SUBROUTINE TAKES 136 CHARACTER STRING AND OUTPUTS LINE
C     AS SELECTED. IF FLAG 0 PRINT VALUE. IF FLAG 1 PRINT SHADE LEVEL
C
      COMMON /A/ LINE(8,137)
      DIMENSION ICHAR(136)
C
C     JUMP TO HEAD OF PAGE, SET 8 LPI, AND CONTINUOUS PRINT
C
      PRINT 41
   41 FORMAT(1H1)
      PRINT 25
   25 FORMAT(1H0)
      PRINT 26
   26 FORMAT (1HT)
      RETURN
      ENTRY MAP2
C
C     TEST OUTPUT STRING REQUIRED
C
      IF(IFLAG.EQ.1)GO TO 42
C
C     PRINT VALUE AS CHARACTER 0 TO 63
C
      PRINT 43,(ICHAR(I),I=1,136)
   43 FORMAT(1X,136R1)
      RETURN
   42 DO 22 I=1,136
      IF(ICHAR(I).GE.0.AND.ICHAR(I).LE.20)22,23
   23 PRINT 24,(ICHAR(J),J=1,136)
   24 FORMAT(43H CHARACTER OUTSIDE RANGE 0 TO 20, STRING IS,/
     1(34(2X,I2)))
      RETURN
   22 CONTINUE
C
C     SET OUTPUT ARRAY TO BLANKS AND THEN SET INDIVIDUAL SHADE CHAR
C
      DO 40 I=1,8
      DO 40 J=1,137
   40 LINE(I,J)=1H
      DO 50 I=1,136
      J=I*8+1
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21)
     1ICHAR(I)+1
    1 CALL L1(J)            $ GO TO 50
    2 CALL L2(J)            $ GO TO 50
    3 CALL L3(J)            $ GO TO 50
    4 CALL L4(J)            $ GO TO 50
    5 CALL L5(J)            $ GO TO 50
    6 CALL L6(J)            $ GO TO 50
    7 CALL L7(J)            $ GO TO 50
    8 CALL L8(J)            $ GO TO 50
    9 CALL L9(J)            $ GO TO 50
   10 CALL L10(J)           $ GO TO 50
   11 CALL L11(J)           $ GO TO 50
   12 CALL L12(J)           $ GO TO 50
   13 CALL L13(J)           $ GO TO 50
   14 CALL L14(J)           $ GO TO 50
   15 CALL L15(J)           $ GO TO 50
   16 CALL L16(J)           $ GO TO 50
   17 CALL L17(J)           $ GO TO 50
   18 CALL L18(J)           $ GO TO 50
   19 CALL L19(J)           $ GO TO 50
   20 CALL L20(J)           $ GO TO 50
```

```
   21 CALL L21(J)
   50 CONTINUE
C
C     SET SPACE FOR LINE 1 AND OVERPPRINT FOR LINES 2 THROUGH 8
C
      LINE(1,1)=1H
      DO 51 J=2,8
   51 LINE(J,1)=1H+
      DO 52 J=1,8
      DO 53 K=2,137
      IF(LINE(J,K).NE.1H )30,53
   53 CONTINUE
      RETURN
C
C     PRINT SHADE LEVELS
C
   30 PRINT 54,(LINE(J,L),L=1,137)
   54 FORMAT(137A1)
   52 CONTINUE
      RETURN
      END
      SUBROUTINE KSET(J)
C
C     THIS SUBROUTINE INSERTS UP TO 8 CHARACTERS INTO THE APPROPRIATE
C     PRINT LOCATIONS TO PRODUCE THE SELECTED SHADE LEVEL
C
      COMMON /A/ I(1096)
      ENTRYL1  $ I(J)=1H                                            $ RETURN
      ENTRYL2  $ I(J)=1H-                                           $ RETURN
      ENTRYL3  $ I(J)=1H=                                           $ RETURN
      ENTRYL4  $ I(J)=1H+                                           $ RETURN
      ENTRYL5  $ I(J)=1H)                                           $ RETURN
      ENTRYL6  $ I(J)=1H1                                           $ RETURN
      ENTRYL7  $ I(J)=1H7                                           $ RETURN
      ENTRYL8  $ I(J)=1HX                                           $ RETURN
      ENTRYL9  $ I(J)=1HA                                           $ RETURN
      ENTRYL10 $ I(J)=1HM                                           $ RETURN
      ENTRYL11 $ I(J)=1HO  $ I(J+1)=1H-                             $ RETURN
      ENTRYL12 $ I(J)=1HO  $ I(J+1)=1H=                             $ RETURN
      ENTRYL13 $ I(J)=1HO  $ I(J+1)=1H+                             $ RETURN
      ENTRYL14 $ I(J)=1HO  $ I(J+1)=1H+   $ I(J+2)=1H'              $ RETURN
      ENTRYL15 $ I(J)=1HO  $ I(J+1)=1H+   $ I(J+2)=1H'   $ I(J+3)=1H.
      RETURN
      ENTRYL16 $ I(J)=1HO  $ I(J+1)=1H+   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1H=                                                    $ RETURN
      ENTRYL17 $ I(J)=1HO  $ I(J+1)=1HX   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1H-                                                    $ RETURN
      ENTRYL18 $ I(J)=1HO  $ I(J+1)=1HX   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1HH $ I(J+5)=1HC                                       $ RETURN
      ENTRYL19 $ I(J)=1HO  $ I(J+1)=1HX   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1HH $ I(J+5)=1HB                                       $ RETURN
      ENTRYL20 $ I(J)=1HO  $ I(J+1)=1HX   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1HH $ I(J+5)=1HB $ I(J+6)=1HV                          $ RETURN
      ENTRYL21 $ I(J)=1HO  $ I(J+1)=1HX   $ I(J+2)=1H'   $ I(J+3)=1H.
      I(J+4)=1HH $ I(J+5)=1HB $ I(J+6)=1HV $ I(J+7)=1HA     $ RETURN
      END
```

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Appendix 2

```
PROGRAM CONVERT
THIS PROGRAM TRANSLATES VIDEO DATA FROM THE ORIGINAL ERTS
TAPE INTO A FORMAT SUITABLE FOR THE CYBER EBCDIC CONVERT ROUTINE
THE 40 CHAR ID RECORD AND THE 624 CHAR ANNOTATION RECORD ARE
PRINTED OUT FOR EACH OF THE TWO STRIPS, BUT ONLY THE TWO SETS
OF VIDEO DATA ARE COPIED ACROSS. THESE CONSIST OF 410 GROUPS
OF 8 CHARACTERS, OF WHICH 2 CHARS ARE FOR EACH BAND 4, 5, 6, 7.
BANDS 4, 5, 6, ARE DECOMPRESSED IN RANGE 0 THROUGH 127, BAND 7
IS LINEAR IN RANGE 0 THROUGH 63.

INTEGER TABLE(129)
LOGICAL*1 INPUT(3296)

SET UP LOOK UP TABLE FOR THE 129 LEVELS. THESE ARE 0 TO 127
AND >127 (OUTSIDE RANGE) WHICH ARE TRANSLATED INTO 64 VALUES

DATA TABLE/63,63,63,63,129,129,130,130,131,131,132,132,133,133,
1134,134,135,135,136,136,137,137,145,145,146,146,147,147,148,148,
2149,149,150,150,151,151,152,152,153,153,162,162,163,163,164,164,
3165,165,166,166,167,167,168,168,169,169,16,16,17,17,18,18,
419,19,60,60,61,61,50,50,38,38,24,24,25,25,11,11,13,13,37,37,
515,15,22,22,5,5,55,55,29,29,0,0,12,12,14,14,
63,3,28,28,1,1,2,2,7,7,208,208,46,46,47,47,31,31,192,192,
730,30,121,121,106,106,161,161,161,161,39/
 J=0
 NUMBER=-1

OPEN OUTPUT TAPE

CALL WRITMT(INPUT,NUMBER)

READ BOTH STRIPS OF INPUT TAPE IN TURN

DO 1 K=1,2
NUMBER=40

READ 40 CHARACTER ID RECORD

CALL READMT(INPUT,NUMBER)

TEST EOF

IF(NUMBER.LE.0)GO TO 7
WRITE(6,2)(INPUT(I),I=1,40)
2 FORMAT(100A)
NUMBER=624
IF(NUMBER.LE.0)GO TO 7

READ 624 CHARACTER ANNOTATION RECORD

CALL READMT(INPUT,NUMBER)
WRITE(6,2)(INPUT(I),I=1,624)
NUMBER=3296
NUMERO=3240

CARRY OUT TRANSLATION OF 2340 LINES IN TURN

DO 3 J=1,2340

READ 3296 CHARACTERS FOR EACH LINE BUT ON OUTPUT DISCARD THE 56
CHARACTERS OF CALIBRATION DATA

CALL READMT(INPUT,NUMBER)
IF(NUMBER.LE.0)GO TO 7
DO 4 I=1,NUMERO
```

Appendix 2 (cont)

```
      IVALUE=I-((I-1)/8)*8
      IF(IVALUE.LT.7)GO TO 10
C
C     MULTIPLY BAND 7 BY 2 TO DECOMPRESS
C
      IF(INPUT(I).GE.0.AND.INPUT(I).LT.128)INPUT(I)=INPUT(I)*2
   10 ITEMP=INPUT(I)
C
C     CLEAR ANY SIGN EXTENSION
C
      ITEMP=IAND(ITEMP,"377)
      ITEMP=ITEMP+1
      IF(ITEMP.GT.128)ITEMP=129
C
C     LOOK UP CONVERSION VALUE IN TABLE
C
    4 INPUT(I)=TABLE(ITEMP)
C
C     WRITE TRANSLATED LINE TO OUTPUT
C
    3 CALL WRITMT(INPUT,NUMERO)
      WRITE(6,8)
    8 FORMAT(12H END OF FILE)
      NUMBER=20
      CALL READMT(INPUT,NUMBER)
C
C     CHECK EOF AT END OF STRIP
C
      IF(NUMBER.GT.0)GO TO 7
    1 CONTINUE
      GO TO 6
    7 WRITE(6,5)J,K
    5 FORMAT(8H ERROR -,I5,22HRECORDS READ FROM TAPE,I3)
C
C     WRITE EOF TO OUTPUT
C
    6 NUMBER=0
      CALL WRITMT(INPUT,NUMBER)
      STOP
      END
```

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Appendix 3

```
      PROGRAM ANALYSE(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE5=/3400)
      INTEGER DATA(63,4),TABLE(3240),CUMUL(63,4)
      INTEGER VAL(63,4),ARRAY(62,80)
      DIMENSION PROB(62)
      DO 60 MM=1,2

      INITIALIZE

      DO 4 I=1,63
      DO 4 J=1,4
      CUMUL(I,J)=0
    4 DATA(I,J)=0

      READ 2340 LINES FOR BOTH STRIPS 1 AND 2

      DO 1 I=1,2340
      READ(5,2)(TABLE(J),J=1,3240)
    2 FORMAT(3240R1)

      ACCUMULATE TOTALS FOR EACH VALUE

      DO 3 K=1,405
      L=K*8
      DATA(TABLE(L-7),1)=DATA(TABLE(L-7),1)+1
      DATA(TABLE(L-6),1)=DATA(TABLE(L-6),1)+1
      DATA(TABLE(L-5),2)=DATA(TABLE(L-5),2)+1
      DATA(TABLE(L-4),2)=DATA(TABLE(L-4),2)+1
      DATA(TABLE(L-3),3)=DATA(TABLE(L-3),3)+1
      DATA(TABLE(L-2),3)=DATA(TABLE(L-2),3)+1
      DATA(TABLE(L-1),4)=DATA(TABLE(L-1),4)+1
    3 DATA(TABLE(L  ),4)=DATA(TABLE(L  ),4)+1
    1 CONTINUE

      GROUP LEVELS IN INCREASING ORDER AND CALCULATE CUMULATIVE TOTALS

      DO 10 J=1,4
      VAL(1,J) = DATA(51,J)
      DO 8 I = 1,50
    8 VAL(I+1,J) = DATA(I,J)
      DO 9 I=52,63
    9 VAL(I,J) = DATA(I,J)
      CUMUL(1,J) = VAL(1,J)
      DO 11 I=2,63
   11 CUMUL(I,J) = CUMUL(I-1,J) + VAL(I,J)
   10 CONTINUE

      JUMP TO HEAD OF PAGE. SET 8 LPI, AND CONTINUOUS PRINT

      PRINT 100
  100 FORMAT (1H1)
      PRINT 101
  101 FORMAT (1H0)
      PRINT 102
  102 FORMAT (1HT)

      PRINT HISTOGRAM AND FREQUENCY TABLE

      PRINT 17
   17 FORMAT(///,38X,5HBAND4,17X,5HBAND5,//,22X,
     15HVALUE,2(3X,9HFREQUENCY,4X,6H TOTAL),/)
      DO 12 I=1,63
   12 PRINT 16,I,((VAL(I,J),CUMUL (I,J)), J=1,2)
   16 FORMAT(15X,5(3X,I8))
      PRINT 100
      PRINT 27
```

Appendix 3 (cont)

```
27 FORMAT(///,38X,5HBAND6,17X,5HBAND7,//,22X,
  15HVALUE,2(3X,9HFREQUENCY,4X,6H TOTAL),/)
  15HLEVEL,2(5X,6HNUMBER,5X,6H CUMUL),/)
   DO 32 I=1,63
32 PRINT 16,I,((VAL(I,J),CUMUL (I,J)), J=3,4)
   DO 7 J = 1,4
C
C     CALCULATE MEAN AND STANDARD DEVIATION
C
   TOTAL = VAL (1,J) * 0.5 + VAL (62,J) * 62.5
   DO 13 I = 2,61
13 TOTAL = TOTAL + VAL(I,J) * I
   AVERAGE=TOTAL/CUMUL(62,J)
   SUMSQ=(0.5-AVERAGE)**2*VAL(1,J)+(62.5-AVERAGE)**2*VAL(62,J)
   DO 14 I = 2,61
14 SUMSQ=SUMSQ+(I-AVERAGE)**2*VAL(I,J)
   SD = SQRT(SUMSQ/CUMUL (62,J))
C
C     CALCULATE NORMAL DISTRIBUTION CURVE OF SAME SD AND MEAN
C     FORMULA AS GIVEN IN MORONEY (1951) P109
C
   DO 15 I=1,62
   XDIFF=(I-AVERAGE)*(I-AVERAGE)
   POWER=XDIFF/(2.*SD*SD)
15 PROB(I) = 1/(SD*SQRT(2*3.14159))* 2.71828**(-POWER)*CUMUL(62,J)
C
C     SET BOTH ACTUAL AND THEORETICAL CURVES INTO ARRAY FOR OUTPUT
C
   DO 19 I=1,62
   DO 19 K=1,80
19 ARRAY (I,K) = 1R
   DO 18 I=1,62
   L=VAL(I,J)/ 5000.+0.5
   IF (L.GT.80) L = 80
   IF (L.LT.1) L = 1
   L=81-L
   ARRAY (I,L) = 1R+
   L=PROB(I)/ 5000.+0.5
   IF (L.GT.80) L = 80
   IF (L.LT.1) L = 1
   L=81-L
   ARRAY (I,L) = 1R-
18 CONTINUE
   PRINT 21,((ARRAY(I,L),I=1,62),L=1,80)
21 FORMAT(16X,62R1)
   PRINT 6
 6 FORMAT(///,40X,13HDENSITY VALUE,///,30X,
  140HVERTICAL SCALE: 1 INCH = 40,000 READINGS)
C
C     PRINT MEAN AND SD
C
   PRINT 5,AVERAGE,SD
 5 FORMAT(/,29X,6H MEAN=,F8.2,8H      SD=,F8.2,//)
 7 CONTINUE
60 CONTINUE
   STOP
   END
```

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Appendix 4

```
      PROGRAM SENSOR(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE5=/3400)
      INTEGER TABLE(3240)
      DIMENSION AVERAGE(6,4),DATA(63,6,4),CUMUL(6,4),TOTAL(6,4)
      DIMENSION CORRN(6,4),AV(4)
C
C       INITIALIZE
C
      DO 4 I=1,63
      DO 4 K=1,6
      DO 4 J=1,4
    4 DATA(I,K,J)=0.0
      DO 14 J=1,4
      AV(J)=0.
      DO 14 I=1,6
      AVERAGE(I,J)=0.0
      CUMUL(I,J)=0.0
   14 TOTAL(I,J)=0
C
C       READ 2340 LINES FOR STRIPS 1 AND 2 AS 780 GROUPS OF 6 LINES
C
      DO 1 N=1,780
      DO 1 I=1,6
      READ(5,2)(TABLE(J),J=1,3240)
    2 FORMAT(3240R1)
C
C       ACCUMULATE TOTALS FOR EACH VALUE
C
      DO 3 K=1,405
      L=K*8
      DATA(TABLE(L-7),I,1)=DATA(TABLE(L-7),I,1)+1
      DATA(TABLE(L-6),I,1)=DATA(TABLE(L-6),I,1)+1
      DATA(TABLE(L-5),I,2)=DATA(TABLE(L-5),I,2)+1
      DATA(TABLE(L-4),I,2)=DATA(TABLE(L-4),I,2)+1
      DATA(TABLE(L-3),I,3)=DATA(TABLE(L-3),I,3)+1
      DATA(TABLE(L-2),I,3)=DATA(TABLE(L-2),I,3)+1
      DATA(TABLE(L-1),I,4)=DATA(TABLE(L-1),I,4)+1
    3 DATA(TABLE(L  ),I,4)=DATA(TABLE(L  ),I,4)+1
    1 CONTINUE
C
C       GROUP TOTALS ON BASIS OF 24 INDIVIDUAL DETECTORS
C
      DO 8 N=1,6
      DO 8 J=1,4
    8 CUMUL(N,J)=DATA(1,N,J)*2+DATA(51,N,J)/2.
      DO 6 I=2,50
      DO 6 K=1,6
      DO 6 J=1,4
    6 CUMUL(K,J)=CUMUL(K,J)+DATA(I,K,J)*(I+1)
      DO 9 I=52,61
      DO 9 K=1,6
      DO 9 J=1,4
    9 CUMUL(K,J)=CUMUL(K,J)+DATA(I,K,J)*I
      DO 12 I=1,6
      DO 12 J=1,4
   12 CUMUL(I,J)=CUMUL(I,J)+DATA(62,I,J)*62.5
C
C       CALCULATE TOTAL NUMBERS FOR 24 INDIVIDUAL DETECTORS
C
      DO 13 I=1,62
      DO 13 J=1,6
      DO 13 K=1,4
   13 TOTAL(J,K)=TOTAL(J,K)+DATA(I,J,K)
C
C       CALCULATE AND PRINT MEANS FOR 24 INDIVIDUAL DETECTORS
C
```

Appendix 4 (cont)

```
      DO 7 I=1,6
      DO 7 J=1,4
    7 AVERAGE(I,J)=CUMUL(I,J)/TOTAL(I,J)
      PRINT 99
   99 FORMAT(1H1)
      PRINT 10
   10 FORMAT(1H1,45X,10HBAND4     ,10HBAND5     ,10HBAND6     ,10HBAND7
     1     ,/,25X,12HSENSOR MEANS,/)
    5 FORMAT(28X,4HLINE ,I1,6X,4F10.3,/)
      PRINT 5,((I,(AVERAGE(I,J),J=1,4)),I=1,6)
C
C      CALCULATE AND PRINT BAND AVERAGES AND SENSOR CORRECTIONS
C
      DO 11 J=1,4
      DO 11 I=1,6
   11 AV(J)=AV(J)+AVERAGE(I,J)
      DO 15 J=1,4
   15 AV(J)=AV(J)/6
      DO 16 J=1,4
      DO 16 I=1,6
   16 CORRN(I,J)=AV(J)-AVERAGE(I,J)
      PRINT 17,(AV(I),I=1,4)
   17 FORMAT(/,27X,8HAVERAGES,6X,4F10.3,/////)
      PRINT 18
   18 FORMAT(26X,11HCORRECTIONS,/)
      PRINT 5,((I,(CORRN(I,J),J=1,4)),I=1,6)
      STOP
      END
```

Appendix 5

```
      PROGRAM MACRO(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE5=/3400,
     1TAPE4=/1600)
C
C     THIS PROGRAM TAKES AS INPUT A MAGNETIC TAPE OF STRIP DATA
C     AND OUTPUTS DATA ARRAY OF HOR * VER ELEMENTS FOR THE FOUR BANDS
C     IN ADDITION IT APPLIES SENSOR CORRECTIONS TO CORRECT FOR STRIPING
C     INPUT TAPE IS LU 5 OUTPUT TAPE IS LU4
C
      DIMENSION VALUE(73,4),SUM(73,4),TOTAL(73,4),CORRN(6,4),IPOSN(4)
      INTEGER TABLE(3240),HOR,VER
C
C     SET SIZE OF OUTPUT ARRAY REQUIRED INTO HOR AND VER
C     HOR VALUE RESTRICTED BY SIZE OF TAPE4 OUTPUT STRING
C
      HOR=73  $ VER=233
      ISTRIPE=1
      PRINT 41
   41 FORMAT(1H1)
C
C     READ IN SENSOR CORRECTIONS
C
      DO 20 J=1,4
      READ 10,IBAND,(CORRN(I,J),I=1,6)
   10 FORMAT(I3,2X,6F5.2)
   20 PRINT 101,IBAND,(CORRN(I,J),I=1,6)
  101 FORMAT(/,20H SENSOR CORRECTIONS-,/,(10X,I3,3X,6F6.2))
      IPOSN(1)=7
      IPOSN(2)=5
      IPOSN(3)=3
      IPOSN(4)=1
      I1=1
C
C     PERFORM PROCEDURE FOR REQUIRED NUMBER OF OUTPUT LINES EQUAL
C     VERTICAL ARRAY
C
      DO 1 L=1,VER
      I2=2340.*L/VER+0.5
C
C     INITIALIZE FOR EACH OUTPUT LINE
C
      DO 22 K=1,HOR
      DO 22 I=1,4
      VALUE(K,I)=0.
      SUM(K,I)=0.0
   22 TOTAL(K,I)=0.0
C
C     PERFORM PROCEDURE TO COMBINE GROUPS OF INPUT LINES INTO A SINGLE
C     OUTPUT LINE
C
      DO 3 I=I1,I2
      READ(5,2)(TABLE(J),J=1,3240)
    2 FORMAT(3240R1)
      IF(ISTRIPE.GT.6)ISTRIPE=1
      J1=1
C
C     PERFORM PROCEDURE TO COMBINE GROUPS OF PIXALS WITHIN EACH LINE
C     FOR OUTPUTTING REQUIRED NUMBER OF CHARACTERS
C
      DO 4 K=1,HOR
      J2=405.*K/HOR+0.5
C
C     ACCUMULATE SUMS/TOTALS FOR 4 BANDS AND APPLY SENSOR CORRECTIONS
C
      DO 24 MX=1,4
      DO 5 J=J1,J2
```

Appendix-5 (cont)

```
      N=J*8-IPOSN(MX)
      NN=N+1
      DO 19 M=N,NN
      IF(TABLE(M).EQ.63)GO TO 19
      IF(TABLE(M).EQ.51)13,14
   13 SUM(K,MX)=SUM(K,MX)+0.5
      GO TO 11
   14 IF(TABLE(M).EQ.62)15,16
   15 SUM(K,MX)=SUM(K,MX)+62.5
      GO TO 11
   16 IF(TABLE(M).LT.51)17,18
   17 SUM(K,MX)=SUM(K,MX)+TABLE(M)+1
      GO TO 11
   18 SUM(K,MX)=SUM(K,MX)+TABLE(M)
   11 TOTAL(K,MX)=TOTAL(K,MX)+1
      SUM(K,MX)=SUM(K,MX)+CORRN(ISTRIPE,MX)
   19 CONTINUE
    5 CONTINUE
   24 CONTINUE
    4 J1=J2+1
      ISTRIPE=ISTRIPE+1
    3 CONTINUE
C
C     CALCULATE MEAN VALUES AND OUTPUT THE CHARACTERS FOR EACH LINE
C     AND FOR EACH OF THE FOUR BANDS TO TAPE
C
      DO 60 I=1,4
      DO 6 K=1,HOR
    6 VALUE(K,I)=SUM(K,I)/TOTAL(K,I)
   60 WRITE(4,69)(VALUE(K,I),K=1,HOR)
   69 FORMAT(200F8.3)
C
C     PRINT THE FIRST OUTPUT LINE AS A CHECK
C
      IF(L.LE.2)PRINT 70,(VALUE(K,1),K=1,HOR)
   70 FORMAT(/,19H FIRST LINE OUTPUT-,/,(10X,10F10.3))
    1 I1=I2+1
      STOP
      END
```

<u>Appendix 6</u>

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```
      PROGRAM PICTURE(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4=/1600)
C
C     THIS PROGRAM IS DESIGNED TO PRINT OUT A MAP OF SELECTED BANDS
C     THE  DATA IS IN A HOR X VER ARRAY ON TAPE 4 WITH EACH LINE 4,5,6,7
C     IN SEQUENCE. FLAGOP IS SET IN THE PROGRAM TO 0 FOR CHARACTERS
C     1 FOR SHADEPRINT. IF 1 A CARD WILL BE READ IN FOR THE CONTOUR
C     FOR EACH OF THE SELECTED BANDS
C
      DIMENSION VALUES(200),MEAN(200),ISTRING(136),IBAND(4)
      REAL ILEV(4),INT(4),LEVELS(8)
      INTEGER HOR,VER,FLAGOP
C
C     SET REQUIRED PARAMETERS
C
      HOR=73 $ VER=233 $ FLAGOP=1
C
C     INITIALIZE
C
      IPOSN = 30
      PIXLINE=200.8/VER
      PIXSIZE=HOR/805.
C
C     READ INPUT BANDS
C
      READ 15,((IBAND(I),ILEV(I),INT(I)),I=1,4)
   15 FORMAT(4(I4,2F8.3))
      PRINT 20,((IBAND(I),ILEV(I),INT(I)),I=1,4)
   20 FORMAT(/,1X,4(I6,2F10.3))
C
C     CARRY OUT PROCEDURE FOR UP TO 4 BANDS
C     ALIGN TAPE INPUT TO CORRECT BAND
C
      DO 12 K=1,4
      IF(IBAND(K).LT.4.OR.IBAND(K).GT.7)GO TO 13
      GO TO (4,5,6,7)IBAND(K)-3
    7 READ(4,1)(VALUES(I),I=1,HOR)
    6 READ(4,1)(VALUES(I),I=1,HOR)
    5 READ(4,1)(VALUES(I),I=1,HOR)
    1 FORMAT(200F8.3)
    4 IF(FLAGOP.NE.1)GO TO 17
C
C     CALCULATE CONTOUR LEVELS FOR THIS BAND
C
      LEVELS(1)=ILEV(K)
      DO 16 I=2,8
   16 LEVELS(I)=LEVELS(I-1)+INT(K)
C
C     READ AND OUTPUT ALL LINES FOR THIS BAND
C
   17 CALL MAP1(ISTRING,FLAGOP)
      DO 2 J=1,VER
      READ(4,1)(VALUES(I),I=1,HOR)
C
C     CLEAR OUTPUT STRING
C
      DO 8 I=1,136
    8 ISTRING(I)=0
C
C     SET VALUES TO INTEGER AND CALCULATE CONTOUR INTERVALS
C
      DO 3 I=1,HOR
      MEAN(I)=VALUES(I)+0.5
      IF(FLAGOP.NE.1)GO TO 3
      DO 9 M=1,8
      IF(VALUES(I).GE.LEVELS(M))9,14
```

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Appendix 6 (cont)

```
    9 CONTINUE
      M=9
   14 MEAN(I)=9-M
C  14 MEAN(I)=M-1
    3 CONTINUE
C
C     CALCULATE NUMBER OF CHARACTERS SLIPPAGE
C
      ICHARS = J*PIXLINE*PIXSIZE
      DO 18 I=1,HOR
      M=IPOSN-ICHARS+1
   18 ISTRING(M)=MEAN(I)
C
C     OUTPUT LINE
C
      CALL MAP2(ISTRING,FLAGOP)
C
C     ADVANCE TO NEXT INPUT LINE
C
      IF(J.EQ.VER)GO TO 2
      DO 11 I=1,3
   11 READ(4,1)(VALUES(M),M=1,HOR)
    2 CONTINUE
      REWIND 4
   12 CONTINUE
   13 STOP
      END
```

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Appendix 7

```
      PROGRAM CORREL(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4=/1600)
      DIMENSION VALUE(200,4),AVERAGE(4),VAR(5,5),VSD(5,5),SD(4)
      DIMENSION N(5),O(5),WW(5),RM(5),LIG(5),EIGV(5,5),ROOT(5),A(5),B(5)
      EXTERNAL SEPAR
      REAL MEAN(4)
      INTEGER HOR,VER
      HOR=73 $ VER=233
      READ 10,((AVERAGE(I),SD(I)),I=1,4)
   10 FORMAT(8F8.3)
      PRINT 4,((AVERAGE(I),SD(I)),I=1,4)
    4 FORMAT(1X,8F8.3)
      DO 7 I=1,4
      MEAN(I)=0.
      DO 7 J=1,4
      VSD(I,J)=0.
    7 VAR(I,J)=0.
      DO 1 L=1,VER
      DO 3 I=1,4
    3 READ(4,2) (VALUE(K,I),K=1,HOR)
    2 FORMAT(200F8.3)
      DO 60 K=1,HOR
      DO 60 I=1,4
      MEAN(I)=MEAN(I)+VALUE(K,I)
      DO 60 J=1,4
      VSD(I,J)=VSD(I,J)+((VALUE(K,I)-AVERAGE(I))/SD(I))*
     1((VALUE(K,J)-AVERAGE(J))/SD(J))
   60 VAR(I,J)=VAR(I,J)+(VALUE(K,I)-AVERAGE(I))*(VALUE(K,J)-AVERAGE(J))
    1 CONTINUE
      DO 54 I=1,4
      MEAN(I)=MEAN(I)/(HOR*VER)
      DO 54 J=1,4
      VSD(I,J)=VSD(I,J)/(HOR*VER)
   54 VAR(I,J)=VAR(I,J)/(HOR*VER)
      DO 6 I=1,4
    6 SD(I)=SQRT(VAR(I,I))
      PRINT 51,(MEAN(I),I=1,4)
   51 FORMAT(1H1,6H MEANS,/,1X,4F10.3)
      PRINT 52,(SD(I),I=1,4)
   52 FORMAT(///,4H SDS,/,1X,4F10.3)
      PRINT 21,((VAR(I,J),I=1,4),J=1,4)
   21 FORMAT(///,22H NON STANDARDIZED DATA,//,
     127H VARIANCE/COVARIANCE MATRIX/,(1X,4F10.3))
      CALL EIGSYM(4,5,4,VAR,ROOT,EIGV,A,B,W,O,WW,RM,LIG,SEPAR)
      PRINT 12,(ROOT(I),I=1,4)
   12 FORMAT(//,13H EIGENVALUES ,/,4F10.4)
      PRINT 13,((EIGV(I,J),I=1,4),J=1,4)
   13 FORMAT(///,13H EIGENVECTORS,/,(4F10.4))
      PRINT 22,((VSD(I,J),I=1,4),J=1,4)
   22 FORMAT(///,18H STANDARDIZED DATA,//,
     127H VARIANCE/COVARIANCE MATRIX/,(1X,4F10.3))
      CALL EIGSYM(4,5,4,VSD,ROOT,EIGV,A,B,W,O,WW,RM,LIG,SEPAR)
      PRINT 12,(ROOT(I),I=1,4)
      PRINT 13,((EIGV(I,J),I=1,4),J=1,4)
      PRINT 99
   99 FORMAT(1H1)
      STOP
      END
```

Appendix 8

```
      PROGRAM EIGENV(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4=/1600,
     1TAPE3=/1600)
C
C     THIS PROGRAM IS DESIGNED TO CARRY OUT A LINEAR TRANSFORMATION
C     OF THE FOUR BANDS ONTO THE FOUR PRINCIPAL COMPONENTS
C     THE EIGENVECTORS AS PREVIOUSLY CALCULATED ARE USED IN THE TRANSFORM
C
      DIMENSION EIG(4,4),VALUE(73,4),EVALUE(73,4),AV(4),SD(4)
      INTEGER HOR,VER
C
C     INITIALIZE
C
      HOR=73 $ VER=233
C
C     READ AND PRINT MEANS AND SDS FOR FOUR BANDS
C     (NOTE- SDS WILL BE UNITY FOR STANDARDIZED TRANSFORMATION)
C
      READ 11,((AV(I),SD(I)),I=1,4)
   11 FORMAT(8F8.3)
      PRINT 12,((AV(I),SD(I)),I=1,4)
   12 FORMAT(1X,8F8.3)
C
C      READ AND PRINT FOUR EIGENVECTORS
C
      READ 1,((EIG(L,I),I=1,4),L=1,4)
    1 FORMAT(4(4F8.4,/))
      PRINT 10,((EIG(L,I),I=1,4),L=1,4)
   10 FORMAT(4(1X,4F10.4,/),1H1)
C
C     CALCULATE FOR ALL LINES
C
      DO 6 J=1,VER
C
C     CLEAR EIGENVALUE ARRAYS
C
      DO 7 K=1,HOR
      DO 7 I=1,4
    7 EVALUE(K,I)=0.
C
C     READ ALL BANDS FOR ONE LINE
C
      DO 3 I=1,4
    3 READ(4,2)(VALUE(K,I),K=1,HOR)
    2 FORMAT(200F8.3)
C
C     CALCULATE ALL FOUR EIGENVALUES FOR EACH VIDEO DATA ELEMENT
C
      DO 4 K=1,HOR
      DO 4 I=1,4
      DO 4 L=1,4
    4 EVALUE(K,L)=EVALUE(K,L)+(VALUE(K,I)-AV(I))/SD(I)*EIG(L,I)
C
C     OUTPUT ONE LINE FOR EACH EIGENVECTOR
C
      DO 5 I=1,4
    5 WRITE(3,2)(EVALUE(K,I),K=1,HOR)
      IF(J.GT.1)GO TO 6
C
C     PRINT FIRST LINE FOR CHECKING
C
      DO 9 I=1,4
    9 PRINT 8,(EVALUE(K,I),K=1,HOR)
    8 FORMAT(//,27H EIGENVECTORS OF FIRST LINE,(/,1X,10F10.3))
    6 CONTINUE
      STOP
      END
```

Appendix 9

```
      PROGRAM VERIFY(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4=/1600)
C
C     THIS PROGRAM CHECKS THE EIGENVECTOR ARRAYS BY CALCULATING
C     THE MEANS (WHICH SHOULD BE ZERO) AND THE VARIANCES
C     (WHICH SHOULD EQUAL THE EIGENVALUES)
C
      DIMENSION VAR(4),AV(4),VALUE(73,4)
      INTEGER HOR,VER
C
C     INITIALIZE
C
      HOR=73 $ VER=233
      DO 7 J=1,4
      AV(J)=0.
    7 VAR(J)=0.
      DO 1 I=1,VER
C
C     READ ALL BANDS FOR ONE LINE
C
      DO 2 J=1,4
    2 READ(4,3)(VALUE(K,J),K=1,73)
    3 FORMAT(200F8.3)
C
C     ACCUMULATING TOTALS
C
      DO 4 J=1,4
      DO 4 K=1,HOR
      AV(J)=AV(J)+VALUE(K,J)
    4 VAR(J)=VAR(J)+VALUE(K,J)*VALUE(K,J)
    1 CONTINUE
C
C     CALCULATE AND PRINT MEANS AND VARIANCES
C
      DO 5 J=1,4
      AV(J)=AV(J)/(HOR*VER)
    5 VAR(J)=VAR(J)/(HOR*VER)
      PRINT 6,((AV(J),VAR(J)),J=1,4)
    6 FORMAT(1X,8F10.4)
      STOP
      END
```

Appendix 10

```
      PROGRAM ARRAY(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4=/1600,
     1TAPE3)
C
C     THIS PROGRAM IS DESIGNED TO PRINT OUT A DISTRIBUTION ARRAY
C     OF POINTS BASED ON THE PRINCIPAL AND SECONDARY EIGENVECTORS
C
      DIMENSION VALUES(200,4),IARRAY(80,40),IHEAD(80),LINE(100)
      REAL ILEV(2),INT(2),LEVEL1(80),LEVEL2(40)
      INTEGER HOR,VER
C
C     INITIALIZE
C
      HOR = 73 $ VER = 233
      DO 8 I=1,80
      IHEAD(I) = I
      DO 8 J=1,40
    8 IARRAY(I,J) = 0
C
C     READ AND PRINT ORIGIN AND INTERVAL VALUES
C
      READ 15, ((ILEV(I),INT(I)),I=1,2)
   15 FORMAT(4F8.3)
      PRINT 16, ((ILEV(I),INT(I)),I=1,2)
   16 FORMAT(1X,4F10.3)
      LEVEL1(1) = ILEV(1)
      DO 20 I=2,80
   20 LEVEL1(I) = LEVEL1(I-1) + INT(1)
      LEVEL2(1) = ILEV(2)
      DO 21 I=2,40
   21 LEVEL2(I) = LEVEL2(I-1) + INT(2)
C
C     READ IN EIGENVALUES FOR EACH LINE
C
      DO 9 L=1,VER
      DO 1 I=1,4
    1 READ(4,2)(VALUES(J,I),J=1,HOR)
    2 FORMAT(200F8.3)
C
C     ALLOCATE TO APPROPRIATE LEVEL FOR EACH EIGENVALUE
C
      DO 3 I=1,HOR
      DO 4 J=1,80
      IF(VALUES(I,1).GE.LEVEL1(J))4,5
    4 CONTINUE
      J = 80
    5 DO 6 K=1,40
      IF(VALUES(I,2).GE.LEVEL2(K))6,7
    6 CONTINUE
      K = 40
    7 IARRAY(J,K) = IARRAY(J,K)+1
    3 CONTINUE
    9 CONTINUE
      PRINT 10
   10 FORMAT(1H1)
      PRINT 11
   11 FORMAT(1H0)
      PRINT 12
   12 FORMAT(1HT)
      DO 40 IJ=1,2
      IK=IJ*20
      IL=IK-19
      PRINT 10
      PRINT 13, (IHEAD(I),I=IL,IK)
   13 FORMAT(8X,20I3)
C
```

Appendix 10 (cont)

```
C     PRINT OUT NUMBERS IN TWO DIMENSIONAL ARRAY
C
      DO 14 I=1,80
   14 PRINT 17,IHEAD(I),(IARRAY(I,J),J=IL,IK)
   17 FORMAT(5X,21I3)
   40 CONTINUE
      DO 19 I=1,80
   19 WRITE(3,18)  (IARRAY(I,J),J=1,40)
   18 FORMAT(40I3)
      PRINT 10
C
C     CALCULATE TOTALS ON PRINCIPAL EIGENVECTOR
C
      DO 25 J=1,80
      DO 23 K=1,100
   23 LINE(K)=1R
      NUMBER=0
      DO 22 I=1,40
   22 NUMBER=NUMBER+IARRAY(J,I)
      NO=NUMBER/20.+1.5
      IF(NO.GT.100)NO=100
      LINE(NO)=1R+
C
C     PRINT FREQUENCY GRAPH
C
      PRINT 24,NUMBER,IHEAD(J),(LINE(K),K=1,100)
   24 FORMAT(16X,I6,I5,1X,100R1)
   25 CONTINUE
      PRINT 10
      PRINT 26,ILEV(1),INT(1)
   26 FORMAT(/,1X,41HPRINCIPAL COMPONENT DISTRIBUTION, ORIGIN=,F8.3,
     115H INTERVAL SIZE=,F8.3)
      PRINT 10
C
C     CALCULATE TOTALS ON SECONDARY EIGENVECTOR
C
      DO 35 I=1,40
      DO 33 K=1,100
   33 LINE(K)=1R
      NUMBER=0
      DO 32 J=1,80
   32 NUMBER=NUMBER+IARRAY(J,I)
      NO=NUMBER/50.+1.5
      IF(NO.GT.100)NO=100
      LINE(NO)=1R+
C
C     PRINT FREQUENCY GRAPH
C
      PRINT 24,NUMBER,IHEAD(I),(LINE(K),K=1,100)
   35 CONTINUE
      PRINT 10
      PRINT 36,ILEV(2),INT(2)
   36 FORMAT(/,1X,41HSECONDARY COMPONENT DISTRIBUTION, ORIGIN=,F8.3,
     115H INTERVAL SIZE=,F8.3)
      STOP
      END
```

Appendix 11

```
      PROGRAM RESID(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE4)
C
C     THIS PROGRAM CALCULATES RESIDUALS OF THE TWO DIMENSIONAL
C     DISTRIBUTION ARRAY OF FIRST AND SECOND PRINCIPAL EIGENVECTORS
C     THE RESIDUAL IS DETERMINED BY CALCULATING THE REGIONAL FREQUENCY
C     AS THE MEAN OF THE SURROUNDING POINTS AND SUBTRACTING IT FROM
C     THE ACTUAL NUMBER OBSERVED
C
      DIMENSION IARRAY(80,40),MEAN(80,40),IHEAD(80)
C
C     INITIALIZE
C
      DO 8 I=1,80
    8 IHEAD(I)=I
      DO 4 I=1,80
    4 READ(4,3)(IARRAY(I,J),J=1,40)
    3 FORMAT(40I3)
C
C     CALCULATE RESIDUALS BASED ON 5X5, 7X7 AND 9X9 REGIONAL ARRAY
C
      DO 68 M=2,4
      DO 1 I=1,80
      DO 1 J=1,40
      TOTAL=0.
      VALUE=0.
      I1=I-M
      IF(I1.LT.1)I1=1
      J1=J-M
      IF(J1.LT.1)J1=1
      I2=I+M
      IF(I2.GT.80)I2=80
      J2=J+M
      IF(J2.GT.40)J2=40
C
C     CALCULATE REGIONAL NUMBER
C
      DO 2 K=I1,I2
      DO 2 L=J1,J2
      TOTAL=TOTAL+1
    2 VALUE=VALUE+IARRAY(K,L)
      VALUE=(VALUE-IARRAY(I,J))/(TOTAL-1)
      MEAN(I,J)=VALUE+0.5
C
C     CALCULATE RESIDUAL
C
      MEAN(I,J)=IARRAY(I,J)-MEAN(I,J)
    1 CONTINUE
      PRINT 5
    5 FORMAT(1H1)
      PRINT 6
      PRINT 7
    6 FORMAT(1H0)
    7 FORMAT(1H )
      PRINT 65,(IHEAD(I),I=1,20)
   65 FORMAT(8X,40I3)
C
C     PRINT RESIDUAL ARRAY
C
      DO 66 I=1,80
   66 PRINT 67,IHEAD(I),(MEAN(I,J),J=1,20)
   67 FORMAT(5X,41I3)
   68 CONTINUE
      STOP
      END
```

ENCLOSURES

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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/8

THE COMPUTATION OF SUN AND STAR OBSERVATIONS USING A CDC 3600 COMPUTER

by

G.D. LODWICK

CONTENTS

SUMMARY

Instructions are given for preparing data for the calculation of longitude and azimuth or declination using a Control Data Corporation 3600 computer.

1. INTRODUCTION

The computer programs described in this Record have been modified from the originals written for the Ferranti 'Sirius' computer (Parkinson, 1963). The first program, code-named TRUENTH, is designed for the evaluation of both the azimuth of a reference mark and the station longitude using the 'altitude method'. The second program, code-named DECLINAT, is for the evaluation of the azimuth of a reference mark, or more usually the magnetic declination, using the 'hour angle method'. For both programs the latitude of the station must be known.

Both programs work to an accuracy of 0.1 minute of arc.

2. DATA INPUT AND OUTPUT

The following conditions apply for both programs:

(a) Latitude is positive or negative according as the station is in the northern or the southern hemisphere. Similarly a northerly solar declination is positive whereas a southerly one is negative.

(b) Longitude is always considered between 0 and 360 degrees measured east from Greenwich, e.g. East Australia 150°, Mexico 245°.

(c) The Greenwich hour angle (G.H.A.) for the sun or a selected star is calculated from the nautical almanac for the time of observation by summing the G.H.A. of the previous hour and that due to the fraction of the hour, which can be read from the appendix.

For sun observations, however, this latter step has been incorporated in the program so that the insertion of only the observation time and the G.H.A. of the last hour in the appropriate positions are required.

Unfortunately the G.H.A. of the sun and of stars increase at slightly different rates (owing to the difference in length of solar and sidereal days); hence, for star observations it is necessary to calculate the G.H.A. fully, leaving blank the time columns for hours and minutes. If it is necessary to distinguish between observations done at the same station within any hour, this can be incorporated in the eight letter name, for example:

AROPA 1
AROPA 2, etc.

Program TRUENTH

Program TRUENTH involves two computations:
(a) azimuth of reference mark
(b) station longitude

The data required are as follows:

1. station name) for identification only
2. date)
3. time (accurate to one fifth of a second if possible)
4. position indication of sun or star east or west of true meridian
5. declination of sun or star
6. latitude
7. altitude of sun or star
8. circle reading of azimuth mark
9. circle reading of sun or star
10. G.H.A. of sun or star

If either the azimuth or the longitude only is required from an observation, it is acceptable to punch the relevant data only. For azimuth, for example, time and G.H.A. will be blank; the correct value of azimuth is computed but the value for longitude will be based on a G.H.A. of zero. Similarly, for a longitude computation, the circle reading of azimuth mark will be blank.

The position indication of the sun or star is required for a unique solution, to distinguish between the two similar triangles on each side of the vertical plane through the meridian. If the observed sun or star is in the eastern sky this should be indicated by a figure 1 in column 24, if in the western sky by a figure 3 (see Appendix A).

The azimuth angle printed out is measured 0° to 360° from north through east.

Program TRUENTH is shown in Appendix B.

Program DECLINAT

Program DECLINAT is designed to evaluate the azimuth of a selected reference mark; however, by substituting the magnetic meridian circle reading for that of the reference mark the magnetic declination can be calculated directly.

The data required are as follows:

1. station name) for identification only
2. date)
3. time (accurate to one fifth of a second if possible)
4. not required
5. declination of sun or star
6. latitude
7. longitude
8. horizontal circle reading of mark or magnetic meridian
9. horizontal circle reading of sun or star
10. G.H.A. of sun or star

No position indication for sun or star is required, as the computer does this by testing the local hour angle. Column 24 (Appendix A) is left blank.

The azimuth angle is given between -180° and $+180^{\circ}$, positive or negative signs indicating respectively east or west of north. This convention is convenient, as DECLINAT is used predominantly for declination calculations. However, when preparing readings from a declinometer, care is required in preserving the sense of both sun and magnetic circle readings, i.e. if the south end of the magnet has been observed (observer facing magnetic north), the circle reading of the direct sun must be inserted; if the north end of the magnetic is observed (observer facing magnetic south), the sun reading must be that of the sun reflected from behind in a mirror.

If this sense has not been preserved, i.e. if the observation has been made towards magnetic north with the sun reflected from behind or towards magnetic south with the sun direct, then add or subtract 180° from the sun circle reading so that the corrected value remains between 0° and 360°, e.g. 30° becomes 210° and 240° becomes 60°.

Diagramatically,

magnetic north observed — magnetic south observed

sun circle reading

+ or $-180°$

sun in front (direct) — sun behind (reflected)

Program DECLINAT is shown in Appendix C.

3. PREPARATION OF INPUT DATA

Blank data sheets have been produced, as shown in Appendix A. Observation data can be entered on these in the field to facilitate the early punching of data cards on completion of the survey.

The data sheets are divided into 99 columns and are used as follows:

Column	Use
1 to 8	Station name
9 to 15	Date (year, month, day)
16 to 22	Time
23 to 24	N (position of sun or star)
25 to 31	Declination (sign considered)
32 to 38	Latitude (sign considered)
39 to 45	Altitude (for TRUENTH) Longitude (for DECLINAT)
46 to 52	Mark circle reading (for TRUENTH) Magnetic circle reading (for DECLINAT)
53 to 59	Horizontal circle reading of sun or star
60 to 66	Greenwich hour angle

Notes

(a) For the station name, any or all of columns 1 to 8 can be used.
(b) The date must be written as year (abbreviated), month, and day, e.g. 650801 is 1 August 1965. Column 9 is left blank for clarity.
(c) Time is printed in hours, minutes, seconds, and tenths of seconds, but if the G.H.A. is calculated fully and inserted (as is invariably done with star observations), the minutes and seconds columns must be left blank or the computer will increment the G.H.A. by the corresponding amount.
(d) The value for N is inserted in column 24.
(e) All angles are to be given in degrees, minutes, and tenths of minutes, without blanks or decimal points.
(f) For latitude and declination, positive signs are redundant.

Examples of data sheets are given in Appendix A.

4. REFERENCES

PARKINSON, W. D. 1963 Machine computation of sun and star observations. Bur.Min.Resour.Aust.Rec. 1963/39.

APPENDIX A

Examples of data sheets

The following stations have been selected to illustrate the common uses of the programs

Station	Program	Calculation
WA102	DECLINAT	declination (sun)
Sandown 1	TRUENTH	azimuth (sun)
Cookhamdean	TRUENTH	longitude (star)
Aropa 1	TRUENTH	azimuth and longitude (sun)
Sandown 2	DECLINAT	azimuth (sun)

STATION (1–8)	YR MH DY (9–15)	HR MN (16–19)	SOS (20–22)	N (24)	DEC (N+/S-) (25–31)	LAT (N+/S-) (32–38)	ALTITUDE OR LONG (39–45)	AZ MARK OR MAGNET AZ (46–52)	AZ SUN (53–59)	GHA HOUR (60–66)
WA102	621107	0741	470		-15520	-33100	116505	274592	191490	289051
SANDOWN 1	520604	1725		3	22292	50388	24010	349335	48371	
COOKHAMD	520408	21		1	19256	51337	35094			303171
AROPA 1	630721	0535	500	3	20368	-6205	26539	22028	149156	235259
SANDOWN 2	520604	17			22294	50388	1097	349334	51055	83300

Notes.

a) For Cookhamdean a star is used; therefore the G.H.A. must be calculated fully before insertion and the minutes and seconds columns left blank. Similarly, although the sun has been used for Sandown 2, the G.H.A. has been calculated fully, so again the minutes and seconds columns are blank.

b) For WA102 and Aropa 1 (both sun observations), the G.H.A. has been inserted for the last hour only and the full time inserted; the machine will increment the G.H.A. to the correct value automatically.

c) For Sandown 1 (no longitude required), blanks have been left for G.H.A. but the time has been inserted (for identification only) to the nearest minute. The longitude here calculated is based on a G.H.A. of zero, plus an increment due to 25 minutes. Similarly for Cookhamdean the correct longitude value is calculated but the value for azimuth is that of a mark with the same circle reading as the star (both 0°), i.e. the azimuth of the star.

APPENDIX B

Program TRULYGH

ORIGINAL PAGE IS
OF POOR QUALITY

```
      DIMENSION A(6),D(6)
      TYPEREAL LHA,LONG
      WRITE(61,20)
   20 FORMAT(11X,7HSTATION,9X,4HDATE,6X,4HTIME,9X,7HAZIMUTH,3X,
     19H LATITUDE,3X,9HLONGITUDE)
      WRITE(61,21)
   21 FORMAT(26X,7HY   M   D,6X,3HHMT,9X,9HS FROM N,//)
    5 READ(60,1)NAME,IYEAR,MONTH,IDAY,IHOUR,MINUTE,SECS,N,(A(I),I=1,6)
      IF(EOF,60)7,8
    1 FORMAT(A8,I3,I2,I2,I2,I2,F3.1,I2,6F7.3)
    8 DO4 I=1,6
      K=A(I)
      B=A(I)-K
      C=B*5./3.
    4 D(I)=(K+C)*3.14159/180.
      X1=SECS/60.
      X4= (MINUTE+X1)*3.14159/720.
      GHA=D(6)+X4
      AZ=ACOS((SIN(D(1))-SIN(D(2))*SIN(D(3)))/(COS(D(2))*COS(D(3))))
      LHA=ACOS((SIN(D(3))-SIN(D(2))*SIN(D(1)))/(COS(D(2))*COS(D(1))))
      IF(N.GT.2)2,3
    2 AZ=2.*3.14159-AZ
      GOTO15
    3 LHA=2.*3.14159-LHA
   15 AZ=AZ+D(4)-D(5)
      IF(AZ.LT.0.)11,19
   11 AZ=AZ+2.*3.14159
   19 IF(AZ.LT.2.*3.14159)14,10
   10 AZ=AZ-2.*3.14159
   14 AZ=AZ*180./3.14159
      L=AZ
      X=AZ-L
      W=X*60.
      IF(GHA.LT.2.*3.14159)13,17
   17 GHA=GHA-2.*3.14159
   13 LONG=LHA-GHA
      IF(LONG.LT.0.)16,12
   16 LONG=LONG+2.*3.14159
   12 LONG=LONG*180./3.14159
      N1=LONG
      Y1=LONG-N1
      W1=Y1*60.
C     BIAS SECS TO AVOID MINUS SIGN IN PRINT OUT
      SECS = SECS + 0.001
      JYEAR=IYEAR+1900
      NA = A(2)
      ZA=ABSF((A(2)-NA)*100.)
    9 WRITE(61,6)NAME,JYEAR,MONTH,IDAY,IHOUR,MINUTE,SECS,L,W,NA,ZA,N1,W1
    6 FORMAT(11X,A8,I8,I3,I3,I6,I3,F5.1,I7,F5.1,I7,F5.1,I7,F5.1)
      GOTO5
    7 CONTINUE
```

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD NO. 1967/116

MACQUARIE ISLAND GEOPHYSICAL OBSERVATORY WORK, 1964

by

G.D. LODWICK

CONTENTS

ILLUSTRATIONS

SUMMARY

The author maintained the BMR seismological and geomagnetic observatories at the Macquarie Island ANARE base during 1964. The instrumentation included a vertical, short-period seismograph, and normal and rapid-run magnetographs.

Regular routine observatory data will be published elsewhere, but data on minor local seismic events, probably not recorded at any other stations, are presented.

1. INTRODUCTION

At Macquarie Island the seismological observatory has been in operation since 1950 and the geomagnetic observatory since 1951. The instruments in operation in 1964 comprised two La Cour magnetographs (a normal-run and a rapid-run instrument) and a vertical-component short-period Benioff seismometer with a BMR recorder.

Gregson (1965) has described the 1963 operations. The author was in charge of the observatories from 20th December 1963 until 9th December 1964, and was succeeded by R. C. Sutton.

Earlier reports such as those of Gregson (1965), van Erkelens (1961), Hollingsworth (1960), and Turpie (1959) include descriptions of observatory buildings, routines, and the installation of equipment.

2. MAINTENANCE

All huts and equipment on Macquarie Island are subject to continual corrosion owing to the very damp atmosphere and rigorous climate. Sand and sea spray whipped up by high winds are blown through the camp almost continuously so that deterioration of buildings presents a very real problem.

Maintenance can be divided into two broad classifications:

1. Station maintenance
2. Observatory maintenance.

Station maintenance

All expedition members are required to assist in the work necessary to maintain and improve the station.

Kitchen and mess duties occur periodically throughout the year. In 1964 during the summer season, with enlarged scientific staff, mess duties occupied four consecutive weeks, but after March they were taken a week at a time. During these periods there is little time for other than essential geophysical work.

In the first months of occupation the works programme, involving erection of new buildings, installation of tanks, etc., demanded considerable time and, throughout the year, Saturday afternoons were generally devoted to regular station duties such as shifting of fuel drums and the stacking of timber and garbage runs. Painting was done as a joint effort by the party during September, October, and November, whenever weather permitted, and seal branding occupied the first week of November.

It should be emphasised that the geophysicist is often expected to spend two days per week or the equivalent on general camp projects.

Observatory maintenance

Magnetic. Owing to priorities assigned by ANARE, the magnetic huts were not painted at all during 1964, but in December they were in fair condition. The exposed western side has been sand blasted almost bare, while on the other parts of the exteriors older layers of paint have peeled off in large sections owing to the dampness of the plywood panels beneath. In wet weather water trickles down the inside walls of the variometer hut, but on no occasion did dampness affect magnetic recording in the hut. With winds up to 103 m.p.h. recorded on the camp anemometer in 1964 no movement of the buildings could be detected, although the records would almost certainly have been affected if the variometer hut had moved.

In January both skylight windows of the absolute hut were removed (the cracked one replaced) to caulk leaks which occurred around the glass during rainy periods, and the western window that had been temporarily sealed with masonite was replaced. During high winds in October a window on the southern face of the hut shattered. This was also replaced.

The door of the absolute hut fitted poorly and vibrations of the building during strong winds were often enough to set it free and swinging wildly. In August the door was removed, about a quarter inch was planed off it, and the lock was renovated.

During the elephant seal breeding season in September the outside instrument shelter was knocked over and the battery box pushed askew. The former was repaired and re-sited and the latter righted. It is strongly recommended that during the breeding season a concerted effort be made to keep the area around the magnetic huts free from female seals by chasing them daily. This will avert problems (access to the area, banging on hut walls, etc.) such as those caused by a harem which developed close to the variometer hut in 1964.

Early in the year an exterior light was fitted to the extreme southern corner of the variometer hut. This was an advantage during the shorter days, as the afternoon magnetic routine was often done after dark. Every precaution was taken to ensure the fittings were free from magnetic material.

Seismic. The condition of the office and darkroom is quite good, but the unlined galvanised iron on the darkroom roof shows extensive patches of rust, especially at the edges, where much has been eaten away. It is hoped that the application of a thick coat of silverfrost in October will have delayed further deterioration, but this roof must be replaced at the earliest opportunity.

Considerable time was spent improving office accommodation and darkroom facilities. Exterior lamps were installed at the top and bottom of the steps leading to the office, with two-way switches at either end. This was of value during the winter and at night. The darkroom light switches were replaced by exterior type switches to prevent shocks received when touched by hands wet with fixer. Power points backed by asbestos were installed in the unlined storeroom, which prevented short circuits in damp weather.

Early in the year a handrail was added to the most exposed section of the steps leading to the office. This measure considerably lessened the risk of being blown off the steps in high winds.

In June a new P.A.X. telephone which included circuitry for automatic fire detection was installed. Detectors were placed in the office and darkroom. The office circuit however, was disconnected in September because it was on an extension from the surgery which was re-sited at that time. The office will be reconnected through the new surgery when it is built in 1965.

Electrical heating was available for the office and vault even during periods of emergency power. The darkroom and office were kept at about 70° F by a thermostatically controlled heater. This assisted in keeping the Mercer chronometer (temperature dependent) at a reasonably constant rate, as well as facilitating thorough record drying. The vault heater was required to prevent condensation on the lenses, which caused seismograph trace fogging. Also the paper is more sensitive as the higher temperature lowers the relative humidity, which enables the trace lamp to be run with lower current, thus increasing lamp life.

Leaks occurred in both the office darkroom section and the vault during 1964. Leaking through the join between the wooden office section and the concrete vault is a perennial problem, and though this leak was caulked in the autumn, leaks reappeared in the spring. During driving southerly rain in winter, leaking occurred between the concrete slabs of the vault roof. Water falling on the recording drum resulted on two occasions in some loss of record. This was a minor leak and no further record loss occurred when the recording unit was relocated on the pier.

During the year cracks in the darkroom and around the darkroom door were blocked to make it light proof, the benches were reorganised and covered with lino to prevent the wood becoming caked with fixer and developer, and the office desk was widened by four inches and covered with lino.

The darkroom water supply caused some trouble during the year. The sink top, which was in poor condition, blocked up occasionally and was replaced. The inlet from the spring on Wireless Hill was periodically blocked with slime, and the only solution to this was to clear out the inlet tank monthly. As well as this the section of pipe buried across the valley to carry overflow to the kitchen tanks, blocked up and had to be dug up.

During winter the temperature often dropped below freezing and on three occasions remained there for about five days. Though only the upper three inches of the darkroom tank froze over, the water supply stopped when the water in the ten-foot connecting pipe froze. In the spring this latter was replaced by bowser hose made of rubber approximately $\frac{3}{8}$ inch thick. The area around the tank outlet and the darkroom inlet have been well insulated and these measures should greatly limit future freeze-ups.

The exteriors of the office, darkroom, and storeroom were thoroughly painted and the insides of the office and darkroom were brightened with suitable colours.

The tools were found to have been greatly affected by e damp salt air, and although still fairly serviceable, were not in od condition. They had been stored in a heated cupboard constructed the storeroom, but early in the year were soaked in oil, wiped with enetrene and set up on a shadow board on the darkroom wall. The air ere is warmer and drier and so should assist in keeping them in asonable working order, but I suggest they be cleaned with penetrene t least yearly.

On two occasions the office radio aerial blew down ring storms. The first time the wire parted at the distant anchor secton, which was easily rejoined, but on the second occasion a considerable sted length in the middle had to be replaced.

4. MAGNETIC OBSERVATORY

agnetograph operation

The instrumentation in 1964 was identical to that in 963 (Gregson, 1965). Routine recording of both magnetographs ontinued with only minor adjustments during the year.

Record losses for the year totalled approximately 135 race hours for the normal-run instrument and 180 for the rapid-run. uch of this was due to mechanical drive failure, although the efocusing of the Z-trace early in the year, three lamp failures, and requent camp power failures contributed significantly to the rapid-un total.

The La Cour clockwork drives for the normal-run agnetograph were generally unsatisfactory. Early in the year these topped on a number of occasions. Each time the drive was taken apart, leaned, and replaced, only to stop again after a limited period, in pite of application of various cleansing agents (alcohol, ether, erosene, watch oil, etc.). When all drives became unreliable a lock-work drive borrowed from a meteorological instrument was odified to drive the recording drum. This was checked thoroughly or magnetic properties, and at the requisite distance from the ariometers had no measurable effect. From then on, no normal-run race loss occurred due to drive failure.

The rapid-run recorder was driven by a Venner ynchronous motor, which was most reliable. Early in the year, owever, sledge trouble occurred intermittently, but this was vercome by thorough cleaning and use of a suitable weight.

It should be emphasised that as much as half of all race loss can be attributed to purely mechanical drive failure. Five seless drives (four normal-run, one rapid-run) were returned to ustralia at the end of the year, and if the present drive system is o be continued, it is recommended that at least some of the bservatory drives be interchanged with Head Office annually. No acilities exist at Macquarie Island to maintain these. Alternatively, enner synchronous motors are considerably more reliable in this limate and had it not been for numerous camp power failures throughout he year one would have been installed on the normal-run recorder.

As these synchronous motors operate on currents of the order of 10 milliamps, it should be neither too difficult nor too costly to have them vibrator-driven from the 6-volt accumulator. The possibility of this as a permanent modification should be investigated.

The La Cour pendulum clock had a somewhat erratic rate throughout the year, varying from day to day depending on wind velocity (shaking the walls), temperature, humidity, etc., but a daily rate of 8 seconds gaining was most common even with the fine adjusting weight wound fully out. To avoid complications arising from resetting the minute hand regularly, and also interpolating time corrections, a different method of clock adjustment was introduced toward the end of the year. The clock was compared with the Mercer chronometer at about 2330 GMT, immediately prior to record change. Then the pendulum was stopped for the number of seconds necessary to set it 3 seconds slow. Because the clock had a general rate of eight seconds per day it would usually be five seconds fast and so could be reset easily. In this way the correction at the beginning of the day was 0.0 minute and at the end of the day rarely exceeded -0.1 minute.

On three occasions the rapid-run trace lamp fused necessitating readjustment and refocus of the light spots.

Early in the year intermittent faults in the absolute time-mark relay were traced to deterioration in the circuit joints and these were re-soldered. Also fluctuations in lamp intensity in the rapid-run unit were caused by poor contacts in the lamp socket and a new lamp holder was installed.

The battery charging circuit was modified to allow continuous trickle charging. This ensured that the electrolyte level was always satisfactory and avoided cell damage by excessive charging rates. Measurement showed that a current of 250 mA greater than the load was suitable; a two-ohm potentiometer in the charging circuit allowed this to be achieved.

Control observations

Absolute observations in 1964 were done with a DCK Kew pattern magnetometer No. 158, QHMs 178 and 179, and BMZ 64. During each changeover the QHMs and BMZ were compared with instruments sent from Toolangi: QHM 177, long-range BMZ 221, as well as proton precession magnetometer MNZ-1 No. 1. Preliminary results indicate that on both occasions the intercomparison observations produced consistent results.

Weekly absolute observations provided good baseline control, and there was little difficulty in carrying these out on reasonably quiet days (1964-65 are Years of the Quiet Sun). Experience showed the most suitable period of the day to be immediately after record change as this was not only the quietest time, but also the period when the sun is at its highest. This was important during the short dull winter days.

Preliminary baseline values are quite steady. On only one occasion was there a marked baseline change. This was a sharp jump which occurred in November when the H variometer was

disturbed during orientation tests. Table 1 includes standard deviations of the observed from adopted values.

Little difficulty was experienced with the absolute instruments except that the QHM 178 thermometer was broken early in the year and replaced by one sent down in March, and on 4th April the BMZ magnetic was bumped while unclamped, resulting in the displacement of the magnet from the knife edge. This was carefully reset and although a small change occurred in neutral division, no detectable baseline change occurred. As in previous years trouble was experienced with breakage of the DCK fibre, as there is no way of clamping it while removing or inverting the magnet. D baseline scatter was noticeable during the year; more reliable results should be given by the Askania declinometer introduced at the end of 1964. The azimuth mark normally used for the D observations was Anchor Rock. The alternative 'Post' mark, used when visibility was poor, was checked for azimuth as soon as possible afterwards, since strong winds moved it slightly from time to time.

Normal-run H and Z scale-value determinations were made weekly and D scale-value determinations three times throughout the year. There is some scatter in these results (see Table 1) but no evidence of overall drift. Note that because the H magnet is not damped, and H is small, the magnet took six minutes to settle, even though the deflecting field is not applied impulsively.

Rapid-run scale-value measurements were made monthly. The H and D scale values remained quite steady but the Z scale value increased from 6.3 to 8.6 through the year (Table 1 and Plate 1).

All determinations were made with Helmhotz-Gaugain coils. The scale values adopted for 1964 are shown in Table 1.

Data distribution

Data reported monthly comprised K-indices and preliminary monthly mean values based on ten selected quiet days. Special effects, sudden commencements, storms, etc. were reported after return to Australia.

Quiet day (Sq) curves

Sq curves were constructed for the first weeks of the year but the variation was very small for H and Z and it was felt that no inaccuracy would result from considering the curves as straight lines; this should be as accurate as using the quiet curve of a day almost a week away as is frequently necessary. For very quiet days the best criterion for 0 or 1 K-scalings is probably 'smoothness'.

The D variometer, being sufficiently sensitive, shows the Sq variation, and curves for D were prepared in the following way:

1. Select four of five quiet days for the month (spread out if possible)

2. Scale mean hourly ordinates

3. Mean these, transfer to graph paper

4. Transfer these ordinates to plastic sheets

5. Construct curve with French curves

Orientation tests

The mean meridian used for November 1964 was 26° 19.9'. The orientation tests were carried out on the H and D variometers of both magnetographs, and the results are shown in Table 2. The accuracy values given in the table are derived from the estimated errors in aligning the coils, measuring deflections, etc.

4. SEISMIC OBSERVATORY

Seismograph operation

Observatory recording continued on from 1963. The instrumentation consisted of a short-period vertical Benioff seismometer and a single-drum BMR recorder. The seismometer period was 1.00 second and the galvanometer period 0.2 seconds.

Time marks (in the form of trace deflections) were obtained from a Mercer chronometer and a mirror-relay in the light source. Some trouble occurred with chronometers during the year. The balance wheel spring of Chronometer 18683 broke in January, 19090 had intermittent contact trouble until these were properly cleaned, and the winding chain of 18789 broke in September; 19090 and 18683 had four-second contacts from 56-60 seconds and hour contacts of twenty seconds between 40-60 seconds. Chronometer 18789 had only minute contacts from 00-05 seconds. This necessitated putting on manual time marks during the day because all minute marks were identical and power failures averaged three or four per week, which made their identification difficult. In fact if the rapid-run magnetograph (with hour marks) had not been driven by the camp power, periods between two power failures on the same day would have been impossible to interpret.

Total record loss for the year amounted to 95 hours. The principal reasons for this were lamp failure on three occasions, leakage of roof above recorder twice, seismometer tests, power failures, and driving motor failure once.

In general the focus of the trace was very good. To obtain this, painstaking care was required when renewing the light source globe after a lamp failure.

Microseismic disturbance due to surf and wind necessitated various attenuation settings. On exceptionally calm days a setting of 28 dB could be used. On normal windy days 30 dB or 32 dB was required and in gales 34 dB was required. Attenuation settings were recorded in the seismic log.

Instrument tests

Annual seismometer tests were carried out in May. They were the determination of free periods, damping, and magnification.

The mass was recentred and aligned, and the period adjusted to 1 second (within 1%).

The seismometer damping was adjusted to give a 17:1 ratio of initial deflection of spot to overshoot. The magnification was determined by the weight lift method using weights of 5 and 10 grams for different attenuation. The results were as follows:

Attenuation	Magnification at 1 c/s
22	9850 ± 50
24	7950 "
26	6200 "
28	4850 "
30	3950 "
32	3150 "
34	2450 "
36	2000 "

Chronometer comparison

In previous years daily corrections have been measured at Macquarie Island at about 1700 EST, the Mercer chronometer being compared with WWV Washington or WWVH Honolulu. This time of day proved the most suitable, reception of both stations generally being very poor during the earlier daylight hours. Invariably reception was best on 5 or 10 Mc/s, but fading during magnetically disturbed periods and interference from stations close in frequency often made reception difficult.

The possibility of comparing the chronometer immediately before record change each day was investigated and it was found that reception of Australian Post Office Time Signal transmission from VNG was usually excellent. These time signals are monitored from Mount Stromlo. The time pips as transmitted are of the same order of accuracy as WWV, but are more accurate on reception since the shorter path distance reduces time lag and dispersion caused by ionospheric variations. This lag for VNG is of the order of one hundredth second compared with one twenty-fifth for WWVH and one fifteenth for WWV. Indeed in the early afternoon it was not unusual to record time differences of up to one seventh second between WWV (15 Mc/s) and VNG. Investigation with directional aerials revealed that on these occasions the signal on WWV was being received on the 'long' path. In general slight differences could always be audibly discerned between VNG, WWVH, and WWV.

VNG broadcasts continuously on 12, 7.5, and 5.5 Mc/s with 1000-c/s pips every second except the 59 of each minute; there are no pips in the first minute of each hour when the call sign and transmission frequencies are broadcast in voice. Though pips in each minute are identical, no ambiguity should arise when the chronometer has a fairly constant daily rate of a fraction of a minute, but as a precaution a weekly 'minute check' can be done at the hour or against WWV or WWVH.

Shocks recorded

Preliminary seismic data were reported to Head Office twice weekly. As in previous years the heavy microseismic disturbance limited the number of shocks recorded. Final analysis of the records using the USCGS data revealed 92 teleseisms. Seven minor earthquakes were felt at Macquarie Island in 1964. In all, phases from 268 earthquakes were identified during the year. A list of those probably not recorded by any other station is given in Appendix 1.

Notes

(a) The major Alaskan earthquake that occurred on 28th March was recorded at Macquarie Island. Several hours later the tide gauge revealed a general rise in sea level on ten inches from the tsunami.

(b) Local earthquakes were felt as one impulse or shudder lasting only one or two seconds. Most of the ground movement recorded on the seismometer lasted less than a minute. An interesting observation is that six of the seven felt quakes occurred in pairs, as may be seen in the following table:

Date	Felt by (18 people total)	Estimated (modified Mercalli)
8th March	11 in camp	III +
18th July	1 in camp	II
28th July	5 in camp	III +
2nd November	17 in camp	IV +
3rd November	2 in camp, 1 at Bauer Bay	III (camp) IV (Bauer Bay)
24th November	2 at Hurd Point	III
27th November	5 in camp	III +

Estimation of felt intensity was often difficult owing to high wind velocity and pounding surf.

(c) Six T-phases were identified positively.

5. ACKNOWLEDGEMENTS

The author is grateful for the general co-operation of the 1964 ANARE party and in particular the assistance of T. W. Gadd and R. O. Nunn for continuing routine recording during his absence on field trips. A special mention is due to N. Stair for providing the clockwork drive which enabled the normal-run magnetograph to operate for the last eight months of the year.

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TABLE 1

Magnetograph data

Magnetograph	Element	Scale value	Standard deviation	
			Scale value	Baseline value
Normal	D	2.35	-	0.4
	H	24.7	0.13	5.1
	Z	20.6	0.09	5.7
Rapid run	D	1.02	0.01	-
	H	5.4	0.02	-
	Z	6.3 - 8.6	0.02	-

D values in minutes, minutes/mm

H and Z values in gammas, gammas/minute

TABLE 2

Variometer magnet orientations

Variometer	Date	Magnet north pole
Normal D	17th November	North, $0.9^\circ \pm 0.3^\circ$ East
H		West, $0.7^\circ \pm 0.3^\circ$ North
Rapid Run D	10/12th November	North, $0.1^\circ \pm 0.1^\circ$ East
H		East, $0.9^\circ \pm 0.1^\circ$ North

APPENDIX 1

Minor Earthquakes recorded at Macquarie Island

Recorded phases of all major earthquakes have been reported to ISRC. These totalled 100, including teleseisms, major local shocks, and the seven felt earthquakes discussed in the text. The following list includes all other earthquakes recorded at Macquarie Island, probably none of which has been recorded elsewhere.

The time listed gives only the day, hour, and minute preceding the first recorded phase (invariably P). The arrival times of other phases, if any, are not given.

December 1963

211018	220701	221603	231219	241801	280245
291557					

January 1964

011307	011502	050955	080015	110202	141049
170624	181608	191700	211405	230130	241249
250900	281942	302205			

February 1964

011315	020059	022312	042233	042258	100145
100347	110035	110041	110550	120331	120553
121541	122236	130010	130035	142046	191520
202257	221212	230305	270233	292359	

March 1964

011308	020333	020435	022247	040702	041121
051819	072015	081408	082049	091809	161416
181259	181722	240108	250224	301022	

April 1964

071330	071934	112022	140600	140820	141120
220834	221706	232045	232059	232120	240605
292121					

May 1964

140601	140923	180601	180644	181321	281133

June 1964

061835	180954	181604	190341	201603	221033
252012	260523				

July 1964

031657	110553	152134	181618	261628	280002
280204	282102	290042	290115	301219	

August 1964

020113	021934	031449	031551	040207	051128
120022	120023	120211	140526	160841	201709
260606	270749				

September 1964

031433	130019	182340	190008	190014	200240
220712	221337	231554	231737	290234	

October 1964

011045	040920	080913	140226	150648	162212
171739	192147	200739	222230	230154	241655
271237	290800				

November 1964

011702	030042	031942	052255	061143	080519
100555	112002	140258	140342	150954	200332
211919	221713	230918	231224	250804	271843
301520					

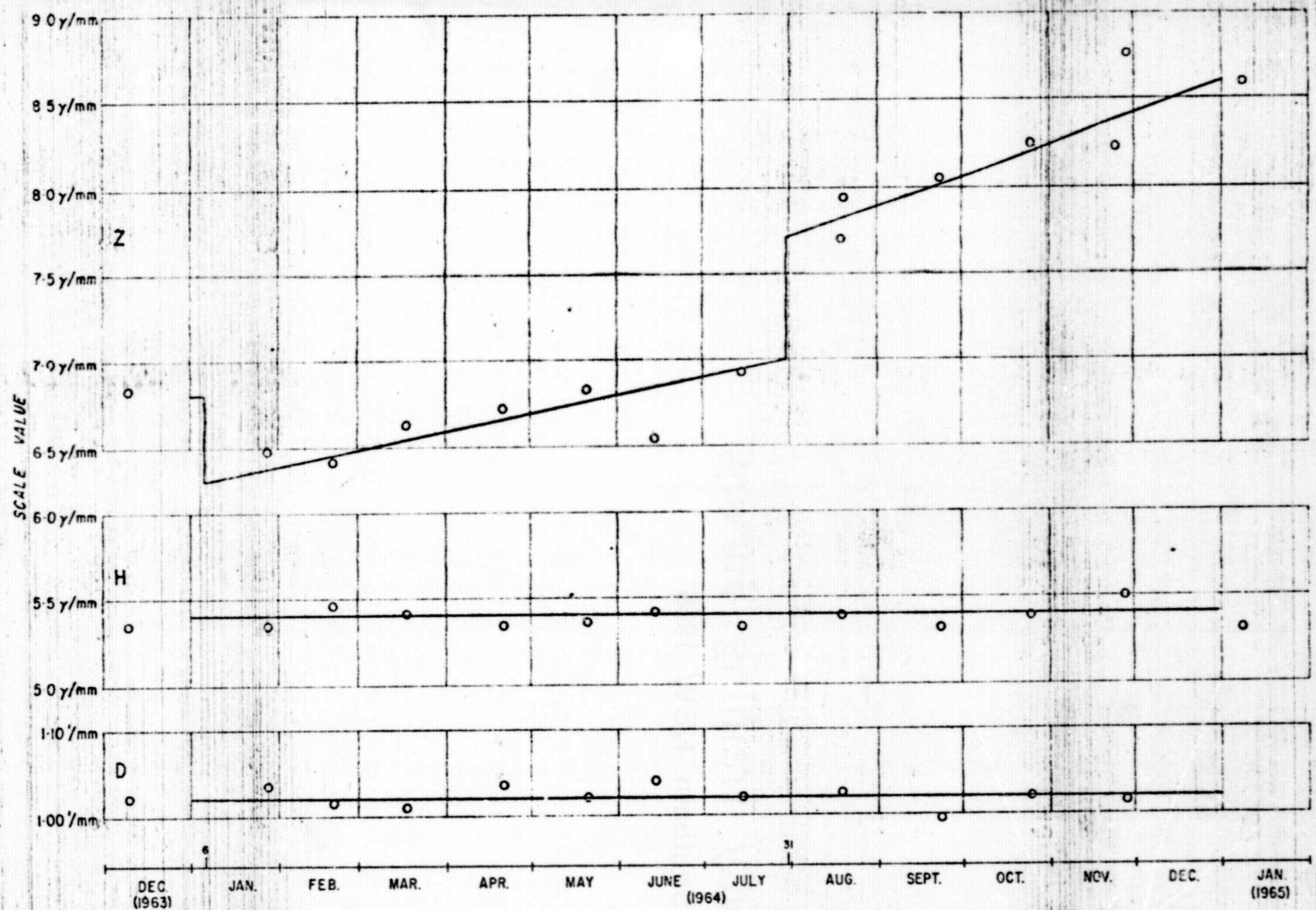
December 1964

051926	070926	081443	081500	081536	092318

Six T-phases were positively identified. Arrival times of the Maxima are given in days, hours, and minutes and tenths of minutes.

December 1963	210709.5	July 1964	260846.7	281855.4
August 1964	300850.3	October 1964	120955.2	
December 1964	060315.9			

PLATE I



MACQUARIE ISLAND 1964

OBSERVED AND ADOPTED STATIC SCALE VALUES
FOR RAPID-RUN MAGNETOGRAPH
(Observation made using Heimholtz coils)

TO ACCOMPANY RECORD No. 1967/116

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G82/2-16

Record No. 1968 / 85

Helicopter Gravity Training Survey,

A.C.T. and Southern NSW 1966

by

G.D. Lodwick and A.J. Flavelle

CONTENTS

ILLUSTRATIONS

SUMMARY

In 1966, the Bureau of Mineral Resources carried out a regional reconnaissance gravity survey of the Australian Capital Territory and part of southern New South Wales. Stations were positioned on a seven-mile grid, the standard error in height observations being 11 ft and in observed gravity 0.1 mgals. The area has been tentatively divided into two gravity provinces, the Monaro Regional Gravity Complex and the Hume Regional Gravity Complex. In the former, the Bouguer anomaly trend is parallel to the coast and is considered to be related to the oceanic thinning of the crust; in the latter the trend of Bouguer anomaly contours is parallel to the structural trend of the Tasman Geosyncline.

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1. INTRODUCTION

In February and March 1966, the Bureau of Mineral Resources carried out a regional reconnaissance gravity survey of the Australian Capital Territory and a part of southern New South Wales, covering the 1:250,000 map areas of GOULBURN, ULLADULLA, CANBERRA, COOTAMUNDRA, and part of WAGGA. A description of the technique of gravity surveying by helicopter is given by Vale (1962) and Hastie and Walker (1962).

The major objective of the survey was to train new personnel in the techniques of gravity surveying by helicopter. In addition, the regional reconnaissance gravity coverage of Australia was extended, thereby assisting in the delineation of major geological structure.

The multiple-base technique of barometric heighting was tested. In view of the various well-defined geographical and meteorological provinces covered (the coastal plain, the inland tablelands, and the Kosciusko plateau) as well as the extensive elevation range from sea level to 6000 ft, it was expected that limitations in accuracy of the present single-base method of barometer levelling would be revealed. The results of this investigation are described in a separate report (Lodwick, in prep).

Appendices 2 and 3 describe work carried out in conjunction with the Division of National Mapping. During the course of the survey ties were made to points established by the National Mapping elevation meter. The results are presented in Appendix 2. Appendix 3 describes investigations carried out to determine the best way of obtaining positive identification on the aerial photographs of the station positions.

Investigation into special operational techniques which may be required in difficult terrain, such as the clearing of helipads, was also carried out. This work is described in Appendix 4.

This report is only a preliminary assessment of the results of the survey.

2. GEOLOGY

The survey covered parts of two distinct geological provinces: the Tasman Geosyncline and the Sydney Basin.

The Tasman Geosyncline

Lower Palaeozoic rocks cover most of the survey area. After deposition and up to the end of the Silurian period these rocks were faulted, folded, and subjected to regional metamorphism. In the late Silurian and Devonian, extensive granitic intrusions with associated contact metamorphism stabilised the geosyncline. Prominent faults such as the Goodradigbee and Murrumbidgee are parallel to the granite intrusions which trend NNW. Granites of Devonian and Silurian age occur extensively in the Tasman Geosyncline. Serpentine crops out in east COOTAMUNDRA and WAGGA along a narrow north-trending zone. From Yass, south through the A.C.T., widespread acid lava flows of middle Palaeozoic age occur. The region was stable during the Mesozoic, but uplift, erosion, and subsidence during the Cainozoic were associated with

...iderable flows of basalt. The sequence of rock types to be found ...the Tasman Geosyncline is summarised in Table 1.

TABLE 1

Geological Sequence - Tasman Geosyncline

System	Rock unit	Lithology	Comments	Thickness (ft)
Quaternary	Alluvium beach and swamp deposit sand	Silt, sand clay, laterite, and travertine	Apparently undisturbed	0-600
Tertiary	Basalt	Fine grained olivine basalt	Flows	-
Permian	Metamorphosed sediments and volcanic rocks	Shale, quartzite basalt, dolomites arkose, minor serpentine	Generally gently folded	12000+
Devonian	Granite and rhyolite	Acid granites and flows of rhyolite	-	
Silurian	Granite	Acid granite	Pluton	-
Ordovician	Metamorphosed sediments	Phyllite, slate shale, quartzite	Intensely folded and cleaved	-

The Sydney Basin

In the southern part of the Sydney Basin the Triassic cover is absent. Table 2 shows the stratigraphy of the Sydney Basin.

TABLE 2

Geological sequence - Sydney Basin (southern part)

System	Rock unit	Lithology	Comments	Thickness (ft)
Quaternary	Alluvium	Sand and swamp deposits	Undisturbed	-
Tertiary	Sediments	Sand, gravel etc.	Flat lying	20
	Basalt	Olivine basalt	Flows	~300
Permian	Milton Monzonite	Monzonite porphyry	Laccolithic intrusion	-
	Termeil Essezite	No data	No data but most likely intrusive	-
	Shoalhaven Group	Sandstone, siltstone, and conglomerate basalt	Intruded by a basalt flow Low east dip	2400
	Clyde Coal	Sandstone, shale, and lenticular coal seams	Occupy isolated pockets in the basement	135±
Ordovician (basement)	Metamorphosed sediments	Folded slates, phyllites, and quartzites	Intensely folded and cleaved	-

Tables 1 and 2 are derived from McElroy and Rose (1962) and Hall (1959).

A narrow Permian basin extends northwards from the Batemans Bay area and underlies the Triassic Cumberland Basin west of Sydney. Formations of the Permian Shoalhaven Group (formerly the Upper Marine Series) crop out north from Batemans Bay. These sediments generally rest unconformably on Lower and Middle Palaeozoic rocks, which crop out south along the coast from Batemans Bay. Coal-bearing strata are known to exist in places at the base of the Shoalhaven Group.

3. PREVIOUS GEOPHYSICAL SURVEYS

The survey described in this Record was the first comprehensive geophysical investigation of the region. Earlier work discussed below were of limited extent and generally aimed at the solution of specific problems in the field of oil and mineral exploration.

Tasman Geosyncline

Aeromagnetic surveys. The Bureau of Mineral Resources carried out a survey of CANBERRA in 1958, and one of GOULBURN in 1965. Long line traverses also cross the survey area. These are Melbourne-Canberra, Canberra-Sydney, Melbourne-Dubbo, Canberra-Dubbo. The results of these surveys are in the form of total magnetic intensity profiles.

Seismic surveys. The Department of Geophysics of The Australian National University has performed seismic crustal investigations in conjunction with the Bureau of Mineral Resources and the Snowy Mountains Hydro-Electric Authority. An approximate figure of 37 kilometres was obtained for the depth to Mohorovocic discontinuity along the line between Lake Eucumbene and the Warragamba Dam (Doyle et al, 1959). A later investigation (Doyle et al, 1966), in which depth charges detonated in the sea off Sydney were recorded by a number of stations in the Snowy Mountains region, gave an average depth to the Mohorovicic discontinuity of 40 kilometres and produced evidence of the Conrad discontinuity at 21 kilometres. Indications are that onshore, in the survey area, the depth of sediments is not great (approximately 1 to 2 kilometres).

A detailed seismic refraction survey of the Lake George area (Polak and Kevi, 1964) investigated the origin and structure of Lake George and obtained information on seismic velocities and basement configuration.

Gravity surveys. The Bureau of Mineral Resources has completed regional gravity traverses throughout the area. Some localised gravity observations have been made in the Snowy Mountain region in connection with engineering projects and in the Lake George area (Kevi, 1964) and at Captains Flat (Sedmik, 1961).

The Department of Geology and Geophysics, University of Sydney, has completed traverses from Bega to Spencers Creek and from Yass to Wallendbeen (Marshall and Narain, 1954), which indicate a normal correlation between negative Bouguer anomalies and granite. The New South Wales Department of Mines has made observations along roads in the western part of the area in a programme designed to establish a statewide network of gravity readings.

The Sydney Basin

Aeromagnetic surveys. The onshore coastal strip from Sydney to Batemans Bay was traversed by L.H. Smart Oil Exploration Pty Ltd. The results are available in a total intensity contour map, and basement depth estimates have been made. The depth estimate values indicate that basement becomes shallower from north to south.

Seismic surveys. L.H. Smart Oil Exploration Pty Ltd undertook a seismic survey in south WOLLONGONG and north ULLADULLA in 1961. This work was abandoned when no useful results were obtained.

Gravity surveys. A semi-detailed gravity survey was performed for L.H. Smart Oil Exploration Pty Ltd in the Jervis Bay area in 1962. The report on this survey has not been published. Most of the work was done in WOOLONGONG and the data for ULLADULLA have not been used as yet.

Boreholes. A number of bores have been drilled near Jervis Bay for the exploration of coal. These include Huskisson No. 1 (840 ft T.D.) Huskisson No. 2 (1900 ft T.D.), and Wandandian (1423 ft T.D.).

4. DESCRIPTION AND INTERPRETATION OF GRAVITY DATA

The Bouguer anomaly map of the area and regional Bouguer anomaly map based on 15-minute means are presented in Plates 3 and 4 respectively at a scale of 40 miles to the inch. The subject area has been tentatively divided into two gravity provinces:

(1) The Monaro Regional Gravity Complex (labelled "A" in Plate 3 and 4).

(2) The Hume Regional Gravity Complex (labelled "B" in Plate 3 and 4).

The -20 milligal Bouguer anomaly contour, with an approximate north-south trend, passing through Goulburn and about 20 miles to the east of Canberra approximates to the boundary between the two provinces. To the east of this the contours have a marked north-north-east trend, while to the west the trend varies north to north-north-west and is conformable with the geological trend in the area.

Monaro Regional Gravity Complex

In the Monaro Regional Gravity Complex, the values of the contour values reduce smoothly from a maximum of +50 mgals at the coast to -20 mgals in south-east GOULBURN. This large regional effect masks out local features, which, however, might be delineated on a residual map. It is postulated that the significant trend parallel to the coast is caused by the oceanic thinning of the crust.

Hume Regional Gravity Complex

The Hume Regional Gravity Complex contains a number of smaller Bouguer anomaly features:

The George Gravity High (B1 on Plate 3). This is a marked positive Bouguer anomaly feature, centred about 3 miles to the north-east of Lake George. It is considered that the feature is caused by basic intrusives, metamorphosed to amphibolite (Kevi, 1964). The feature correlates in its central part with basic intrusive rocks metamorphosed to amphibolite and it is postulated that feature B1 delineates the extent of these rocks.

The Canberra Gravity Low (B2). This is a large arcuate feature with a minimum Bouguer anomaly value of less than -40 mgals, which occupies the western part of CANBERRA. The western boundary of the feature is clearly defined by a decrease in Bouguer anomaly of 20 milligals in 4 miles. The centre of the gradient parallels the Goodradigbee Fault,

which is offset about four miles to the east. The eastern edge of the 'low' is less well-defined, but correlates generally with the Deakin Fault in the north and the Queanbeyan and Murrumbidgee Faults further south. It is postulated that the cause of this 'low' is related to the large granite mass known as the Murrumbidgee Batholith. In contrast it should be noted that extensive outcrops of granite in south-east CANBERRA do not correlate with Bouguer anomaly 'lows'.

The Cootamundra Gravity High (B3). This 'high' consists of two elongated Bouguer anomaly 'highs', the eastern one of which is south-east of Cootamundra and continues less markedly south along the western border of CANBERRA; the western 'high' trends north-north-west from north-central WAGGA. The most positive parts of the Bouguer anomaly correlate with mapped areas of serpentine and it is therefore postulated that feature B3 delineates subsurface basic intrusions.

Gravity 'lows' have been mapped on south-west COOTAMUNDRA (B4), central COOTAMUNDRA (B5), central-east WAGGA (B6), and north-central GOULBURN (B7). It is postulated that features B4, B5, and B6 are caused by acid igneous rocks and B7 by relatively light metamorphosed sediments. All four features appear to have their major development outside the survey area and therefore have not been named.

5. CONCLUSIONS

Throughout the area, mapped areas of basic and ultrabasic rocks correlate with Bouguer anomaly 'highs', whereas the relation between Bouguer anomalies and known granite masses is rather ambiguous. The Murrumbidgee Batholith appears to correlate with a large negative Bouguer anomaly feature, but in other parts of the survey area, various granites show no such correlation. This may indicate a fundamental difference in the origin of granitisation, rather than of batholithic origin.

On a regional scale the Bouguer anomaly pattern correlates well with the observed geology and crustal structure derived from seismic evidence. Near the coast where the crust may be expected to become thinner as the deep ocean comes close to land the positive regional Bouguer anomaly increase from west to east is consistent with this hypothesis. Further inland the trend of the Bouguer anomaly contours is parallel to the regional structure within the Tasman Geosyncline. It is therefore concluded that the regional structure in the Tasman Geosyncline is reflected in the Bouguer anomaly pattern.

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APPENDIX 1

Survey statistics

Helicopter hours:	206.01	
Total days:	57.50	
Unserviceability days:	18.25	
a. Mechanical	Nil)	
b. Stand-down (Mandatory BMR days off).	8.00)	18.25
c. Other	Nil)	
d. Weather	10.25)	
Days not required:	2.00	
Days traversing - useful:	30.25)	
Days traversing - work abandoned:	1.75)	
Days miscellaneous usage:	5.25)	
(e.g. work connected with helipad cutting, long transits, micro-barometer tests)		
Loops:	83	
Loops re-flown:	3	
Tie flights:	4	
Follow-up flights:	2	
Total equivalent loops:	92	
Area covered:	20,000 sq. miles	
Trainees - party members:	Townsend, D. (1/2 - 11/2) Leiwick, G. (7/2 - 30/3) Kirby, K. (1/2 - 30/3) Shirley. J. (1/2 - 30/3) McAvoy, W.J. (1/2 - 30/3)	
Trainees - long term:	Hopkins, A. (5/2 - 19/2) Student Mathews, J. (16/2-17/2) (22/2-2/3) Helicopter Utilities Pty Ltd Milson, J. (15/3 - 24/3) Whitworth, R. (15/3 - 24/3) Branson, J. (21/3 - 25/3) Heyland, P. (21/3 - 29/3) Helicopter Utilities Pty Ltd Jones, B. (25/3 - 31/3)	

Trainees - short term:

Brown, W.	(1/3 - 2/3)
Moss, J.	(7/3 - 9/3)
Robertson, C.	(7/3 - 9/3)
Turpie, A.	(15/3-18/3)
Allen, G.	(15/3-18/3)
Jones, P.	(24/3-26/3)
Brown, A.	(24/3-26/3)

APPENDIX 2

Comparison of barometric and elevation meter heights

During the course of the survey, ties were made to some of the gravity stations with the National Mapping elevation meter. The elevation meter work was done by J. Maddern of the Division of National Mapping and was a separate project.

Table 3 sets out elevation values obtained by the barometer and by the elevation meter. The elevations of stations 6606/0235 and 66 06.9009 will be field checked. A standard deviation for (elevation meter elevation - barometer elevation) was calculated and found to be 19.0 ft. If station 6606.0235 is omitted and the bracketed value of 6606.0820 is used then the standard deviation is 9.3 ft. Since the standard deviation of the elevation meter values is of the order of 2 to 3 ft and that of the barometer values is by network analysis 11.0 ft then the result of 9.3 ft is considered reasonable.

TABLE 3

EM Station Number	EMR Gravity Station Number	Elevation Meter Value (feet) A	Barometer Value (feet) B	A-B (feet)	Comments
EM/C65/8	6606/9028	3153	3143	10	
C65/9	" 0262	2466	2460	6	
C65/11	" 0244	1771	1773	-2	
C66/1	" 9035	1885	1896	-11	
C68/1	" 9026	2571	2575	-4	* This station will
C69/1	" 0235	*2650	2728	-78	be field checked
C69/2	" 9025	2273	2271	2	
C70/2	" 9033	2024	2006	18	
C70/7	" 0820	**2019	2060 (2026)	-41 (-7)	
C71/2	" 0816	1419	1418	+1	**Bracketed values (2026)
C71/3	" 0631	2190	2205	-15	and (-7) obtained if
C72/1	" 9027	1855	1845	+10	a smoother diurnal curve
C73/1	" 0243	1817	1818	-1	used. The actual
C73/2	" 9024	1536	1526	+10	diurnal shows large
C74/1	" 0257	1677	1671	+6	pressure changes from
C74/2	" 9011	***1480	1537	-57	reading to reading and
C75/2	" 0160	1199	1193	+6	it is suspected that
C75/3	" 0161	981	983	-2	the instrument was faulty.
C75/5	" 0103	1081	1092	-11	***The stations were not
C75/6	" 9009	****981	1004	-23	at the same point.
C75/9	" 9013	955	955	0	****This station will be
C75/10	" 9014	1137	1131	+6	field checked.
C75/12	" 0108	1105	1115	-10	
C76/2	" 0057	1083	1092	-9	
C76/3	" 0056	973	968	+5	
C76/4	" 0164	833	824	+9	
C76/5	" 9006	803	792	+11	
C76/6	" 0053	982	980	+2	
C77/1	" 9007	1325	1335	-10	

APPENDIX 3

Station photography

The elevation data collected on helicopter gravity surveys are used by the Division of National Mapping for the compilation of topographic maps. The usefulness of this data is enhanced if the position of each station as identified on aerial photographs can be positively checked.

When the station is occupied by the gravity observer its position is marked on an aerial photograph by means of a pin prick. The investigations by the Division of National Mapping were directed towards devising a second and more positive means of station identification on the aerial photographs. A report by K. Leppart of the Division of National Mapping describing the investigation is attached:

INVESTIGATION IN METHODS OF OBTAINING A PHOTOGRAPHIC RECORD OF THE POSITION OF BMR GRAVITY STATIONS

K. Leppart

The aim of the investigation is to work out an economic method of recording the positions of BMR gravity stations by photographic means in order to transfer them to high altitude survey photographs.

Three methods have been investigated:

Method 1. At time of helicopter gravity survey, each gravity station in a 1:250,000 area, or part thereof, to be marked uniquely with reasonably permanent material. On completion of the gravity survey of this area all marked stations to be photographed with a 35-mm camera from a fixed-wing aircraft. Photographs to be taken near-vertically from an altitude which will bring the scale of the 35-mm photography within the range of a differential stereoscope in order to transfer the marked station position stereoscopically from the 35-mm photographs to the survey photographs.

Method 2. Use of Polaroid camera. A polaroid exposure to be taken of the selected unmarked station site from a height of 500 ft before landing at the station. The exact position of the gravity station is then pricked on the print after landing and the station number written on the back of it. The transfer of the position of the gravity station from the Polaroid print to the survey photograph can be done by inspection only. A stereoscopic transfer is not possible owing to the large difference in scale of the two photographs, which is outside the range of a differential stereoscope.

Method 3. Use of 35-mm camera with f = 30 mm at time of helicopter gravity survey. The gravity station is to be marked by temporary marking material (paper towel, white calico) at time of observation. After take-off, the helicopter is to rise

to not less than 500 ft above ground and a near-vertical photograph is to be taken of the marked station. Transfer of marked position from enlarged exposure to survey photograph by inspection of detail.

ppraisal of methods

Method 1. This is the best of the three methods, but is very ostly. Marking material per station is approximately $4. Lost helicopter flying time is between 5 and 15 minutes per station because of marking ethod. A special photo-flight has to be arranged at the end of the urvey. This method would give the best results because a stereoscopic ransfer of the marked station could be obtained. The failure rate ould be very low. Expenditure per station is estimated to be in excess f $20. This method is not recommended on economic grounds.

Method 2. The application of this method would result in only ne print without a negative. Polaroid cameras with f = 100 mm are not vailable. The area photographed by a polaroid camera is smaller than ne taken with an f = 28 mm, 35 x 24 mm camera. It is rather a messy rocedure to fix and dry the polaroid print in a crowded helicopter. Misidentifications of the unmarked gravity stations are to be feared. The cost would be about 30 cents per print. This method is not recommended because of an anticipated high incidence of misidentification of stations.

Method 3. This involves the temporary marking of the gravity station at the time of the survey with cheap material in a unique pattern. This can either be done by the helicopter pilot at no loss of flying time or by the observer with little loss of time. Tests conducted on the Canberra 4 Blue Loop have shown that an L-shaped marker of paper towelling can be pinned to the ground in about one minute. Material costs would be about 10 cents per station plus the costs of film, developing, and two enlargements, which amount to 20 cents, making a total of 30 cents per station. The time it takes a helicopter to reach 500 ft above ground varies considerably owing to wind conditions, height above sea level, and weight of load. On the average it may take one minute. The total loss in flying time due to delay while pinning down the marking material and due to rising to 500 ft above the station may amount to $2 per station. This brings the total expenditure per station to $2.30*. For a 1:250,000 map area with 200 stations, the application of this method would cost approximately $500. This method is recommended for adoption by the BMR Gravity Section.

Details of recommended method

Type of camera. Any camera with a focal-plane shutter, with f = 30 mm, and using a negative size of 35 mm x 24 mm.

Marking material. White paper towel $7\frac{3}{4}$ inches wide is used to form an L or V of dimensions as shown in Figure 1 below. The paper to be pinned down by at least six roofing nails with cardboard or other soft material washers between the paper and the head of the nail. The corner of the L or V to point north.

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* Experience has shown that the cost of photography by method 3 is very much less than the $2-30 estimated by Mr. Leppart. A.J.F.

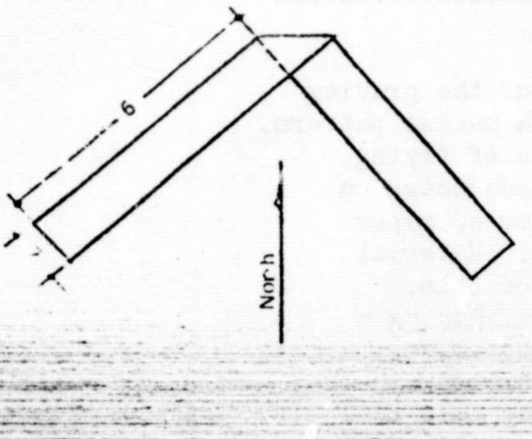
Film. Any brand 35-mm black and white film with an ASA rating of [illegible]. In adverse conditions faster films could be used. There should be one film for each loop contained in its own film cassette.

Exposure time. Maximum time for exposures taken from the helicopter to be 1/200 of a second.

Altitude of helicopter at time of exposure. The exposure to be taken from not less than 500 ft above ground.

Exposure log. A log is to be kept of the exposures on each film: it should state 1:250,000 map area name, the number of the 30-minute square, and loop colour. It should list the exposures in the right sequence with gravity station number as well as any pertinent remarks. A sample log sheet is shown below.

Identification of films. Before a loop is commenced, a photograph should be taken of a blackboard on which the sheet name, the 30-minute square number, and the loop colour is written in white chalk. This should be the first exposure on each film. (See Figure 2 below).



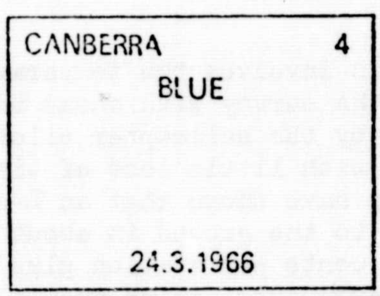


Figure 1

Figure 2

It is essential that the photograph of the marked gravity station is taken as near-vertical as possible. This can be achieved by flying straight at the mark and banking the helicopter at the moment it is above the mark and then taking the photograph at that time.

On completion of the loop, the film cassette containing the exposed film is to be clearly labelled with the map area name, number of 30-minute square, and loop colour. There will be four films per 30-minute square and 24 films per 1:250,000 map area.

The points and other points common to two or more loops should be photographed every time a reading is taken. This will ensure that the sequence in the gravity reading records and the film exposures is the same.

The films need not be developed in the field if the aforementioned procedures are adhered to.

After the films have been developed the numbers of the gravity stations are to be written on the negatives in accordance with the film log. This can be done with black drawing ink or black Chinagraph or Omnichrom pencil.

Two enlarged prints of each exposure including the blackboard one are to be made. Minimum size of enlargement to be 3 x 4 inches; maximum size is to be 4 x 6 inches.

The Division of National Mapping is to be supplied with one set of prints and a list of heights of stations. They will arrange for copying of information marked on the survey photographs by the BMR observer, i.e. the position of the pricked hole denoting the supposed station position and the station number.

Sample of film exposure log

Map area: CANBERRA

Loop: 4

Loop colour: Blue

Date: Thursday, 24th March 1966

Time: 1430 hrs - 1730 hrs

Camera: Nikon, f = 28 mm

Exposure	Station	Remarks
1	Blackboard	
2	Blank	
3	0887	
4	9066	
5	0872	Near fence
6	Blank	
7	0873	
8	0874	
9	0889	Mark in shade of tree
10	Blank	
11	9087	
12	0888	
13	0887	

APPENDIX 4

Establishment of helicopter landing pads

In south-east CANBERRA (on flight 6) the only fixed elevation point near the cell centre was the Mount Bettowynd trig. station. This point was unsuitable for gravity purposes because of the large terrain factor. However, the surrounding area is extremely rugged and its disadvantage as a gravity point was considered to be outweighed by the amount of elevation control it would provide.

An examination of the aerial photographs of the point showed that heavy timber would preclude a landing by helicopter. In addition, the steepness of the slope was such that it would not be feasible to land nearby and walk in. It was therefore decided to provide access to the point by constructing a helipad.

Mount Bettowynd is essentially a linear east-west trending ridge, some five miles long. The culmination on which the trig. point is sited is at the western end. The western slope of the ridge is gentle, heavily timbered, and about four miles long.

The helipad was to be about 50 ft wide and 250 ft long, extending north-south across the ridge. The work was to be done by two people using a chain saw. It was anticipated that the slope up the mountain would be too steep for the people to carry a chain saw and fuel and at the same time make reasonable progress. This equipment was therefore lowered to the ground from a hovering helicopter.

An acceptable helipad took 2½ days to construct (i.e. 40 man-hours). One person operated the power saw while the other one dragged branches and sawn-up tree trunks out of the area. The conclusion derived from this exercise is that the construction of helipads in heavily timbered areas consume a large amount of time and labour and should only be made for access to control stations.

MONASH UNIVERSITY

COMPUTER CENTRE

A TECHNIQUE FOR AUTOMATIC CONTOURING AEROMAGNETIC FIELD SURVEY DATA

by

G.D. Lodwick
and
J. Whittle

November, 1970

SUMMARY

This paper describes a technique which has been developed to contour aeromagnetic survey data or other types of field data collected in the form of linear parallel traverses. The original data is plotted first in plan view and then in cross section to check for errors in any of the three co-ordinates. Then by fitting in the least squares sense a curve of suitable order to the point under consideration and a selected number (n) of the preceding and following points high frequency irregularities in the values of the data points (generally referred to as 'noise') can be minimized. In this way values can be adjusted for all but the first and last n points in each traverse. Next, the essential points of each traverse can be selected (maxima and minima for example, by using the first derivatives of the fitted curves) and these supplemented by a selection of 'fill-in' points, the density of which is determined by the variations in the original profiles, and average spacing limited by the offset distance between traverse lines. Experience with aeromagnetic data indicates that this method will permit up to 5 out of 6 points in each traverse to be deleted with the remaining points defining a profile which agrees in detail very closely to the original. The points finally selected can then be contoured directly (Lodwick and Whittle, 1970). The programs are written in Fortran and are in use on a CDC 3200 computer utilizing a CALCOMP 30 inch off-line plotter. Results have shown that the contours produced using this technique agree remarkably well with those plotted from all the original data points, with a reduction in computer time to as little as one-quarter the original. Indeed the method has proved to be less expensive than currently used contouring techniques, while the final contours honour the original data points accurately.

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1. INTRODUCTION

At Monash University it has proved profitable both in terms of efficiency and economy to develop an automatic contouring package which can be used to contour field survey data - the contouring of field reconnaissance gravity data (Lodwick and Whittle, 1970) is an example. In general terms, however, it would not be unduly difficult to continue contouring such maps using well-established hand-drafting techniques. However, there exists a class of data where the generation of point values occurs so rapidly, and presentation of the data in visual form for decision making is required so promptly after surveying, that the application of hand methods to produce such maps is no longer feasible. Into such a class falls aeromagnetic survey data. Here traverses of the order of 400 line miles can be flown in a single day, generating as many as 16,000 point values. Clearly detailed hand contouring with such a rate of production of survey data would be a mammoth task.

Already, of course there exist automatic techniques which will contour such data collected as regular point values in parallel traverses. These appear in the main to use the well-known technique of translating the original values to the points of a regular grid, which is in turn contoured with established programs. The problem here, however, is that a decision must be taken concerning economy and accuracy of the final map. Where the regular grid is quite fine, computer time will be rapidly consumed, particularly where an on-line plotter is utilised, and this will rapidly escalate the cost of production. On the other hand, the selection of a less dense grid, while keeping costs down, will result in a degradation of the original information, since extreme values will only be preserved where they coincide with grid points, and in general the values of the original data will not be 'honoured' in detail, by contours so produced.

However, by plotting profiles of samples of aeromagnetic data it became clear that within each traverse only a small proportion of the data comprised 'key' points, e.g. maximum or minimum values for the traverse, or points demarking significant change in slope. It followed that by selecting these key points, and where necessary, choosing intermediate ones to achieve an average spacing(which while unimportant in terms of defining major changes in slopes are required to fix intermediate gradients) a considerable proportion of the original data could be deleted, while at the same time preserving intact the specific features of each traverse. The data to be plotted thus transforms from a network of regular traverse data into an irregular framework of data points which can be readily contoured by an existing package (Lodwick and Whittle, 1970). Again, it should be emphasised that because the contouring package will contour directly irregularly spaced data, selection of the stations in this way will preserve in detail the features of the map area.

2. REMOVAL OF ORIGINAL DATA ERRORS

With the arrival of data from the field it has been found essential to plot up the original points in plan view to highlight errors in station position and in cross section to indicate errors in point values. The data can then be corrected, using a straightforward averaging method, or by obtaining from the field partly recalculated values of the erroneous observations. The elimination of survey errors produces results such as Fig.1 and Fig.2.

3. SMOOTHING AND SELECTION OF ORIGINAL POINT VALUES

In a comprehensive paper, Savitzky and Golay (1964), discuss the elimination of the noise component in data values obtained from basically continuous physical experiments. In it is described how values at a central data point are adjusted using the method of least squares, resulting in considerable reduction in the noise component of the original data. Further, the least squares calculations may be carried out simply in the computer by convolution of the data points with properly chosen sets of integers. Savitzky and Golay have derived these sets of integers for up to the fifth derivative for polynomials of degree two through five, and for fitting to up to twelve points on either side of the point of calculation. Their illustrations appear to indicate clearly that a suitable selection of degree of polynomial combined with a carefully chosen number of data points will act as an excellent filter to smooth the noise fluctuations while at the same time introducing minimum distortion into the recorded data.

Whilst their technique has been specifically designed for regularly spaced data in the co-ordinate being measured (i.e. time or distance) our experience has been that variations in the linear distribution of the points of the order of three or four percent have no appreciable effect on the calculated value. Furthermore our results seem to indicate that the noise component in the type of data with which we have dealt, has been considerably less than in the examples they have quoted. It has thus been found sufficient to fit curves of low degree to a small number of adjacent data points. For example the values of the points plotted in profiles in fig.3, adjusted from fig.2, have been evaluated by fitting a third order polynomial to the seven points centred on the point of calculation. Again in this way the slope of the smoothed profile at each data point is calculated using the constants of convolution for the first derivative. Change in the sign of the gradient between calculated points indicates the existence of either a maximum or minimum and the point closest to the local extremum is selected by choosing the one with the smallest absolute value of the first derivative.

From inspection of the original profiles, the number of points required to define in detail the original profile is decided, and where the distances between local extrema exceed the desired average spacing of points, intermediate data values can be inserted to provide reasonable coverage for each traverse, using a simple algorithm. In fig.3 each selected point is indicated by '+'. It can be clearly seen that the deletion of the points plotted '-' will result in negligible distortion of the original profile.

4. RESULTS

Unfortunately no aeromagnetic data was available for publication. However, points and values were specially prepared similar to real data - points within traverses occurring four to each offset distance - with the features of the area being designed to be at least as complicated as any actual maps contoured so far.

In order to make a realistic comparison contours were prepared using all data points with their original values, fig.4. It can be seen that the most important and significant features tend to be somewhat obscured by minor fluctuations as the contours respond to irregular variations (possible 'noise') in adjacent data points. This so-called 'herring-bone' effect, is most significant in contours extending parallel to each traverse, due to the station spacing within traverse being approximately one-quarter the offset distance between traverses. This effect does not reflect the actual surface defined by the drawn contours, but is due to the method of sampling of data.

Contours drawn from the selected data points are shown in fig.5. The most striking result is a marked increase in the clarity of the features, due to a more uniform sampling of the data. Furthermore the important original features have been preserved - the peaks and hollows occur precisely as in the original, their magnitudes closely approximate those of the original observations - while the slopes and trends outlined by the intermediate slopes compare closely to those defined by the original data. In the example expressed in fig.4, the number of points in each traverse has been reduced to approximately one-fifth of the original.

5. CONCLUSION

The method outlined in the preceding pages has proved efficient and economic in relation to other methods currently in use for contouring linear traverse-type data. The fact that Monash University has previously developed package which will contour irregularly spaced data points permits a selection of points within each traverse which convey the maximum information, while those which are of less significance can be neglected. The technique is being used in the preparation of field aeromagnetic data and results so far indicate that accuracy in the contouring can be maintained while at the same time costs can be reduced by as much as 75 per cent.

6. REFERENCES

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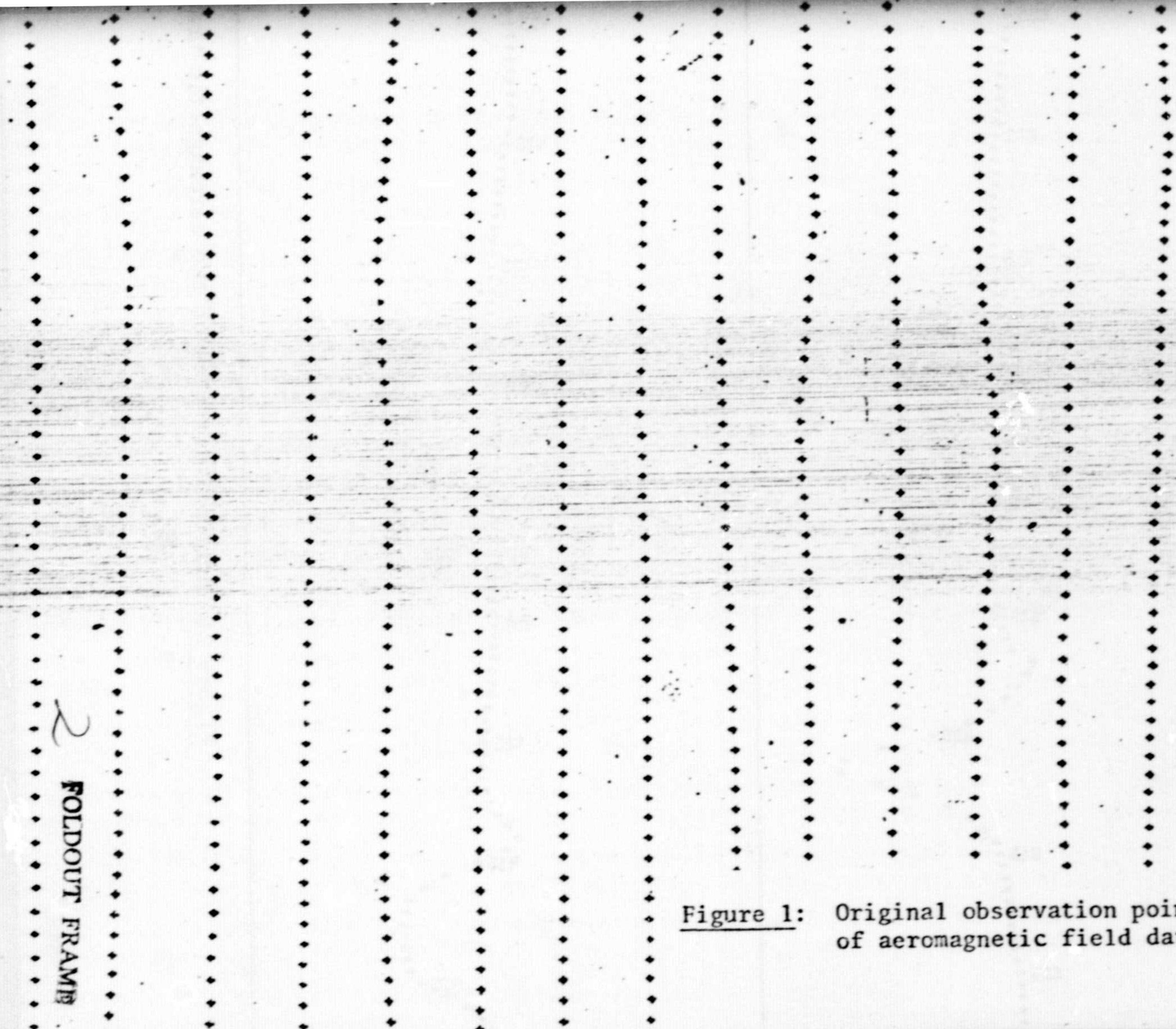

Figure 1: Original observation points of aeromagnetic field data.

2

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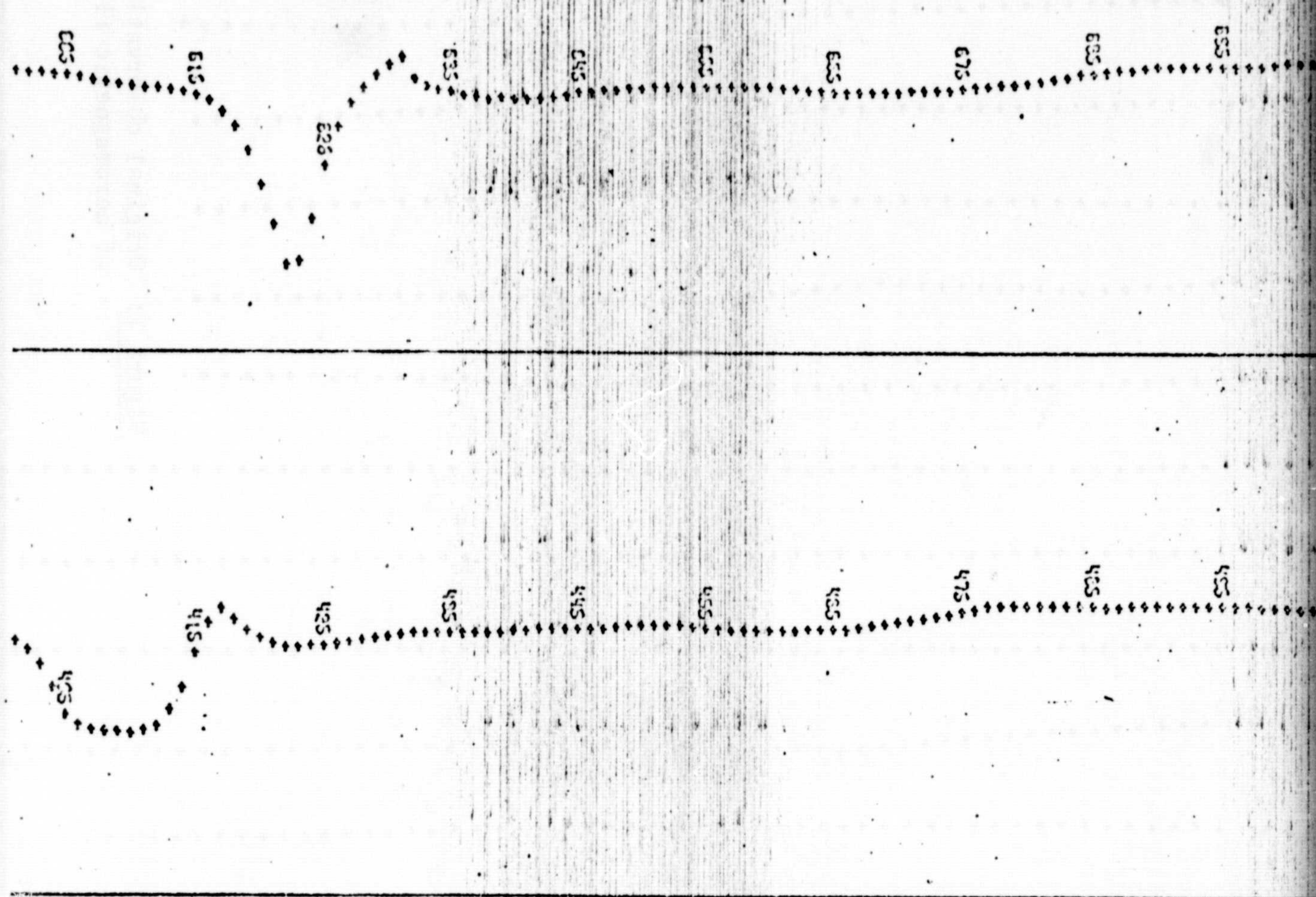

Figure 2: Original profiles of two aeromagnetic traverses.

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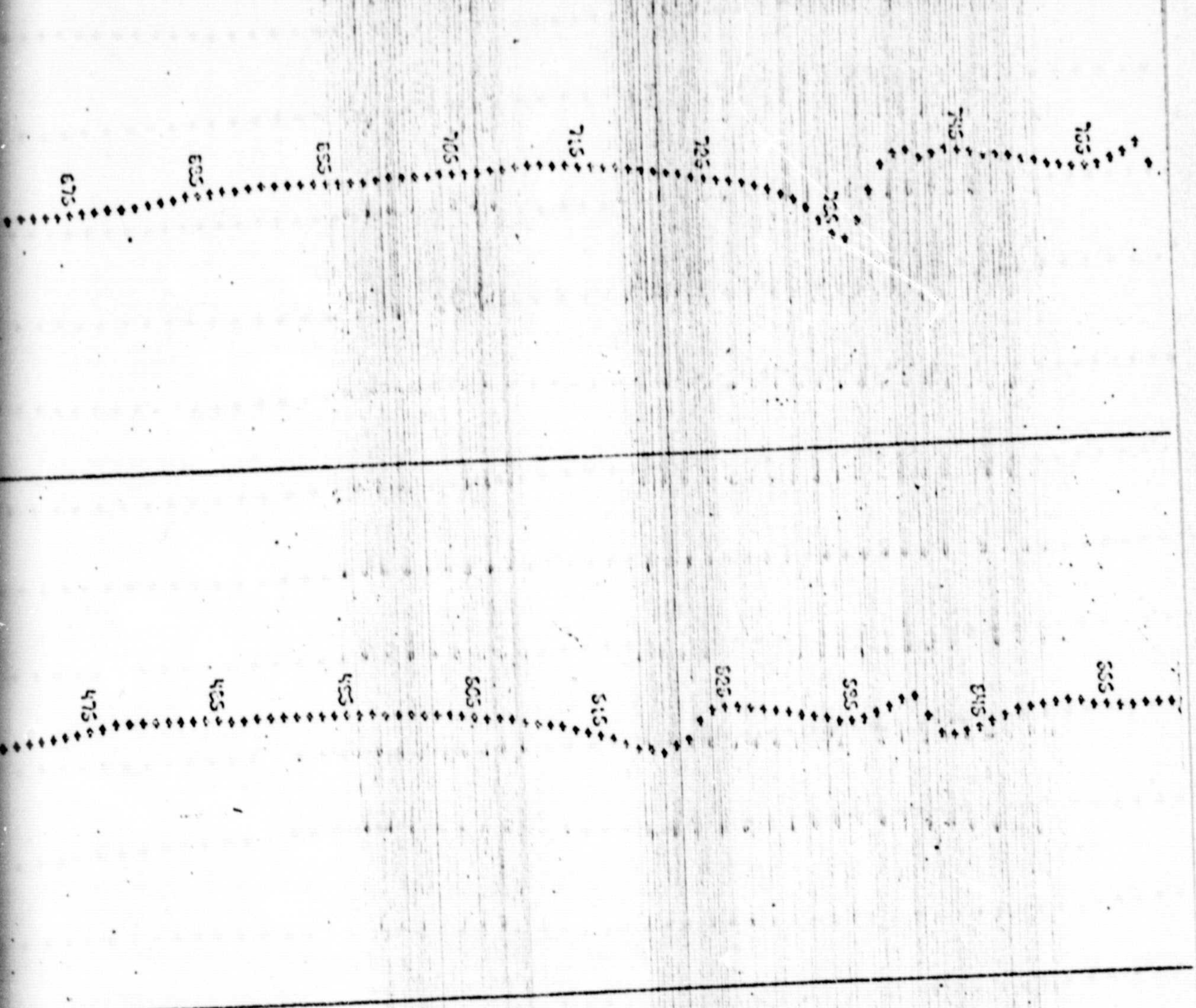


aeromagnetic traverses.

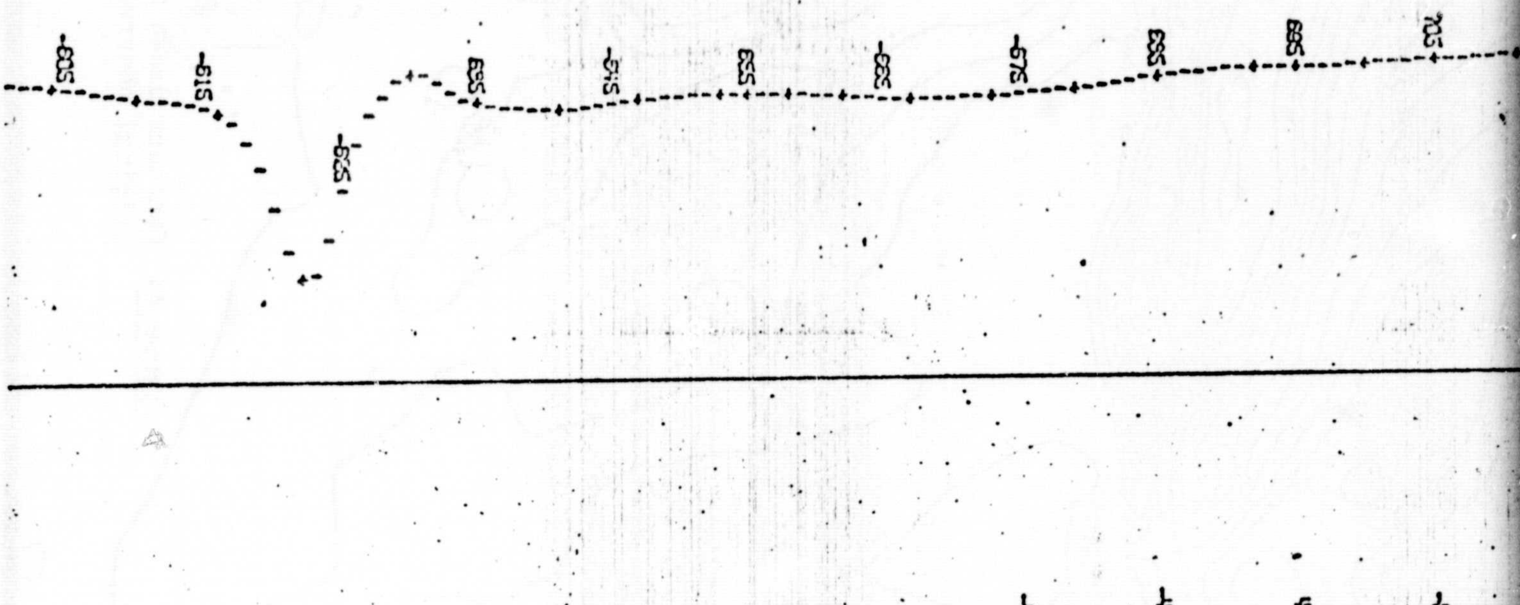
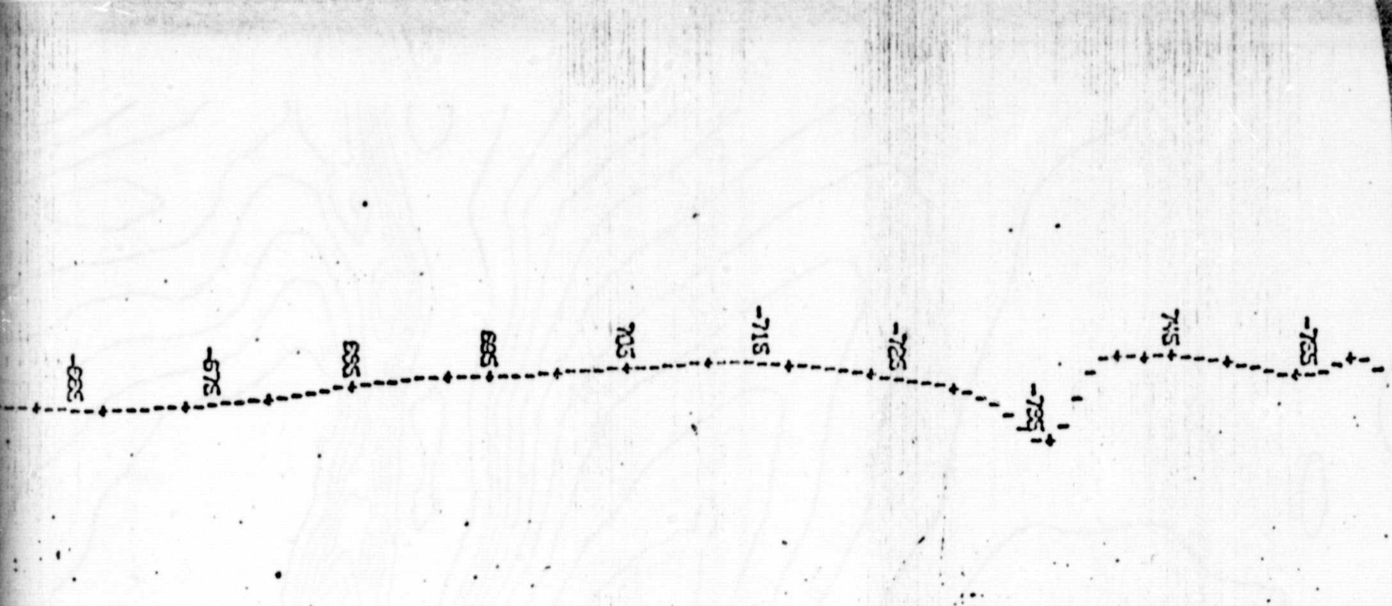


Figure 3: Adjusted profiles of the aeromagnetic traverses of figure 2, with selected points indicated by '+'.



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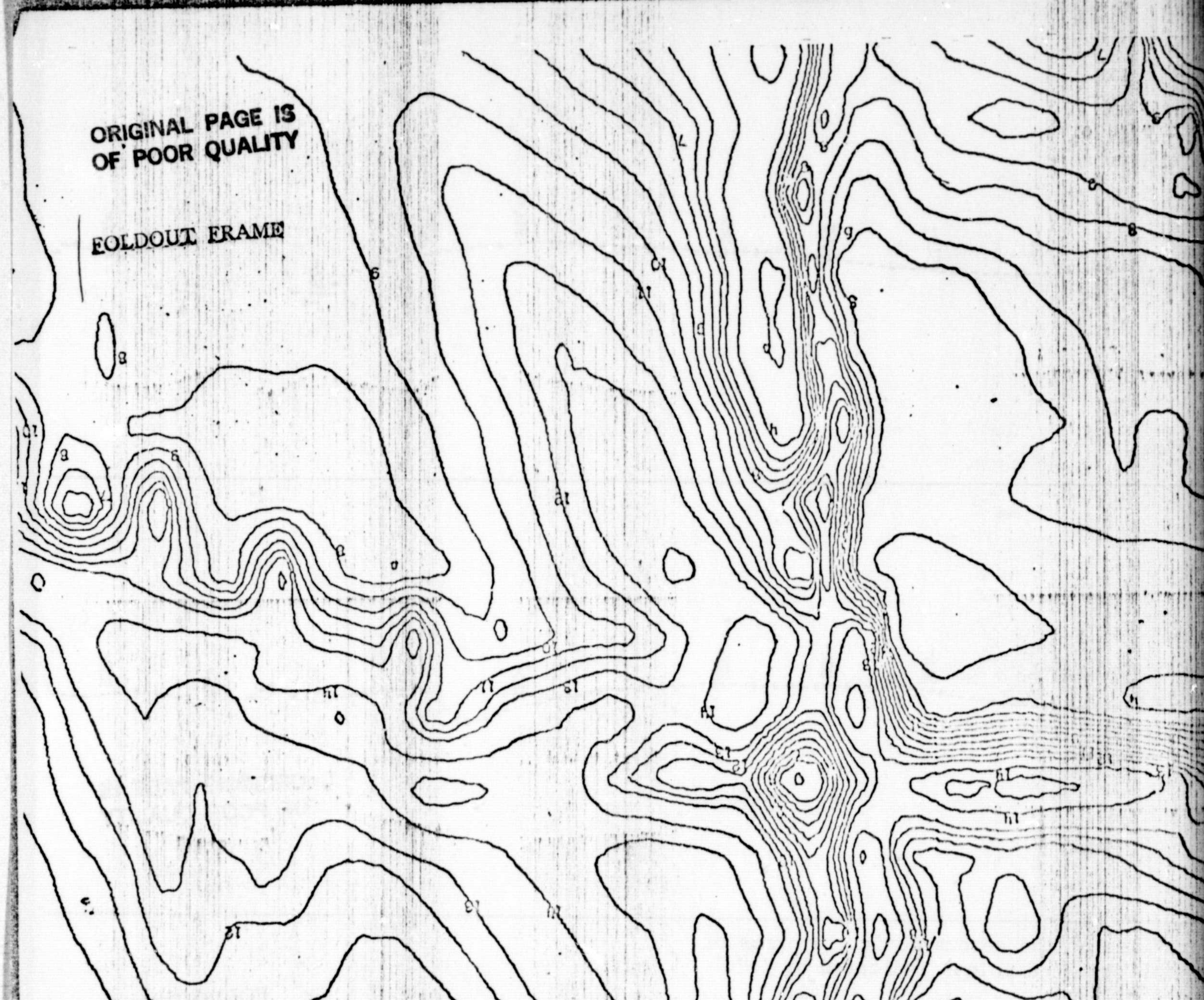

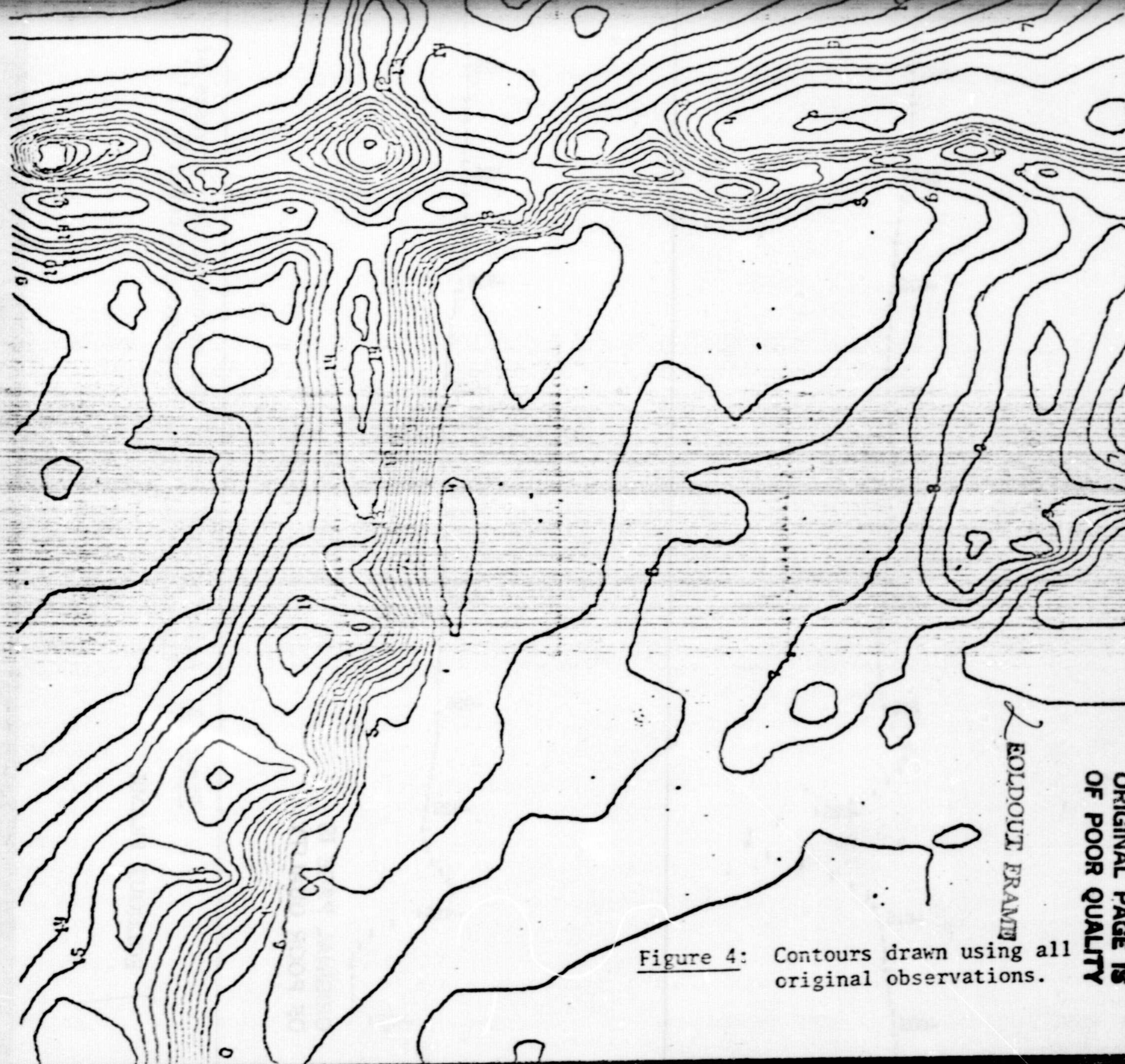

Figure 4: Contours drawn using all original observations.

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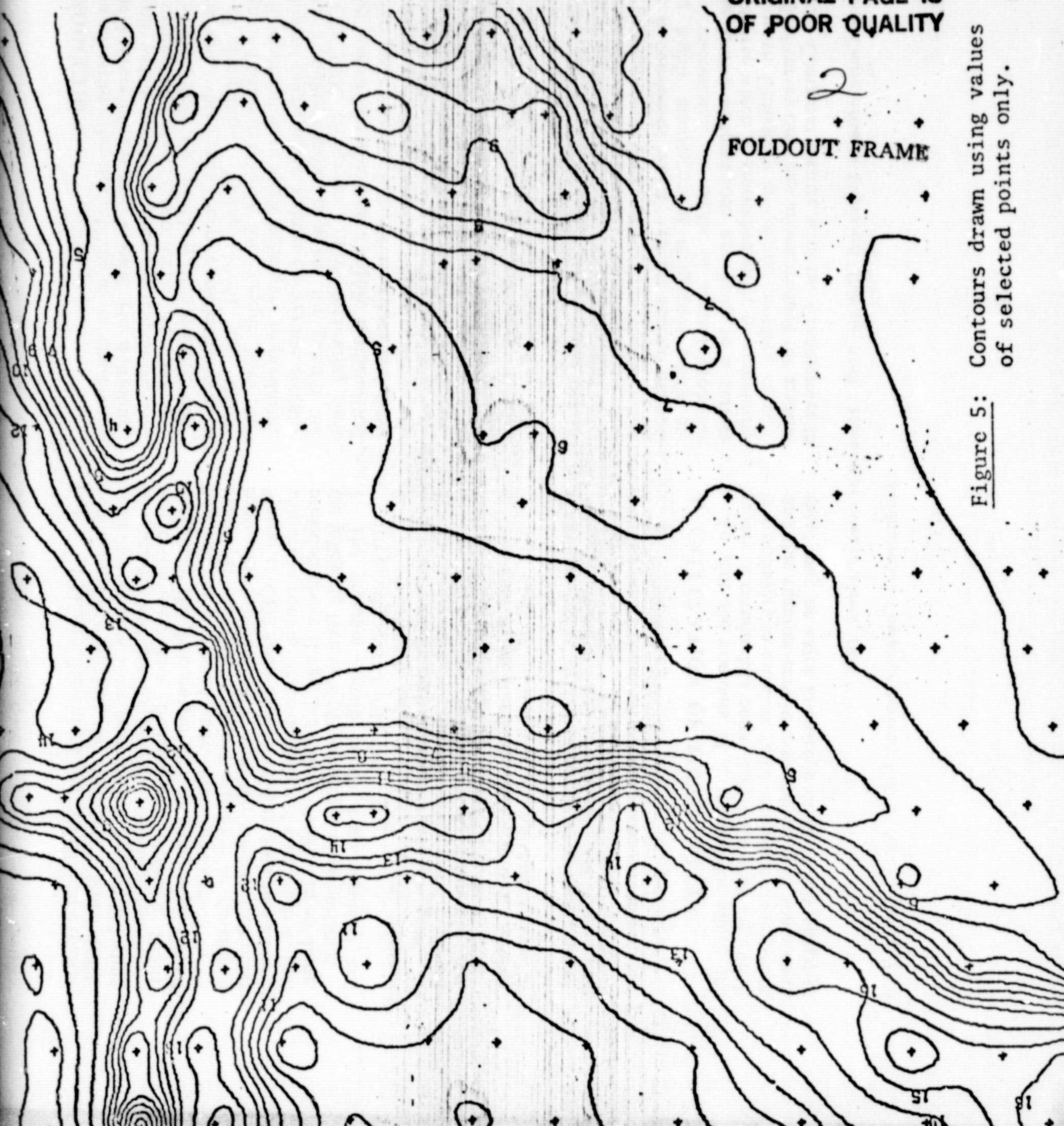

Figure 5: Contours drawn using values of selected points only.

A Technique for Automatic Contouring Field Survey Data

By G. D. Lodwick and J. Whittle *

This paper describes a technique which has been developed to contour field survey data using a digital computer. With irregularly spaced data the method has the advantage that the original observations are contoured rather than the calculated values of a regular grid. Each contour is created in discrete steps with each successive step being positioned by use of calculated values at two points on either side of the projection of the previous step. For each point the value is obtained by fitting a surface to the nearest observations and using the value of the surface at that point. Theoretically, the surfaces considered may be of any degree, though in practice use of weighted planes has been found to combine necessary accuracy with speed. By suitable selection of the number of observations used in the evaluation at a point, contours can be made to agree closely with those drawn by established hand techniques. Use of an overlaying mesh facilitates the commencement and termination of contours. The programs are written in Fortran and are in use on a CDC3200 computer, utilizing a CALCOMP 30-inch off-line plotter. Experience has shown that the production of maps by this technique is efficient and economic in relation to other methods, the principle advantage being in the speed with which quite complex maps can be prepared.

1. INTRODUCTION

In general terms, the desirability of machine contouring field survey data is well known. Hand drafting, though still widely used, is generally expensive and time-consuming, and often inconsistent. It is not surprising therefore that the problem of automatic contouring is one which has been considered from a number of disciplines. Maine (1966), and Maine, Hinksman and Seaman (1967), for example, have considered the application of such techniques to producing meteorological maps, while Palmer (1969) has recently developed a multi-purpose program for general use with a CDC3600 computer. For contouring very irregularly spaced observations a highly mathematical method has been produced by Pelto, Elkins and Boyd (1968), while a portmanteau package has been prepared by Calcomp (1968).

In the main, however, previous methods for contouring irregularly spaced data have adopted either of two approaches. In one method the values of a regular grid are first calculated using filtering or other mathematical techniques to permit contouring with established programs. A difficulty here, however, is that unless the regular grid is quite fine, usually requiring a program which is cumbersome and time-consuming, the resultant contours will often not pass through original points of equivalent value even though the data is considered exact. In the second method, requiring highly mathematical techniques which are generally uneconomic in terms of central processor time, the known observations are fitted to a surface of high degree which is smoothed prior to contouring.

At Monash University a specific problem of contouring field survey data has arisen through the association of the Computer Centre with the Commonwealth Bureau of Mineral Resources and geophysical exploration companies working in Australia. Since 1963, computer systems have been in use for the reduction of magnetic and gravity surveys, including barometric and co-ordinate data (Bellamy and Lodwick, 1968). Previously the final output has consisted of a plotted base map at a selected scale, which was contoured by hand. It was thus a logical extension to develop a contouring program oriented to the Monash Computer System (a CDC3200 with an off-line 30-inch Calcomp plotter) to contour three-dimensional data, such as that provided above (Legg and Brent, 1969). In so doing, the following factors were considered of importance:

1. The program should handle both regularly and irregularly spaced data similarly.
2. For observation data considered exact, contours should pass through points of equivalent value.
3. There should be no discontinuities in the contours.
4. In regions where point values are rare the contours should behave 'reasonably'.
5. The final results should be consistent with currently used methods in which maps are hand-drawn by experienced draftsmen.
6. Where points, or sets of points have known standard errors, the programs should be able to adjust for these.
7. The use of computer central processor time should be minimized to reduce cost.

2. CALCULATION OF POINT VALUES

To plot the contours of a surface for which the values of certain data points only have been measured, it is necessary to calculate values at intermediate points, and this requires certain assumptions. In some cases there may be extra knowledge of the likely shape of

* *Computer Centre, Monash University, Clayton, 3168.* *Manuscript received March, 1970.*

he surface but discussion here is limited to the situa-ion where the only information is provided by the bserved values. The object is to display by contours calculated surface which is the best estimate of the eal surface sampled through the data points. The alculated surface should match the measured data alues within the range of the likely error of the data oints, while using the lowest spatial frequencies (least urface fluctuations) consistent with this. Spatial fre-uencies higher than this are unjustifiable artifacts of he calculation scheme. The minimum spatial wave-ength will be directly related to the distance between djacent data points, and to the variation of observed values in relation to the probable errors.

If a method of calculation is used which is inde-endent of horizontal scale then the variation of spatial wavelength with data point density can readily be chieved by calculating the value at a point from a pre-et number (n) of the observations nearest. As the oint of calculation changes so the n observations con-idered will change and, unless discontinuities are to ccur, the weight accorded to the most distant of he n points must always be zero. The simplest xpression which will give such a weighting is $(d_n - d_i)/d_i$ where d_n and d_i are the distances to points n and i respectively. Further, if the k^{th} derivative of he calculated surface is to be continuous, then the k^{th} erivative of the weights given to an observation must pproach zero as the distance of the data point from he point of calculation approaches that of the n^{th} most istant point. The simplest formula to achieve this is $((d_n - d_i)/d_i)^k$.

Where observations are regarded as being exact, the bove expression is quite suitable, since the weight of n observation is infinite when the point being evalu-ated coincides with its position. The calculated surface will thus coincide with the values given by all data oints so that contours derived from this surface will lways pass on the 'correct' side of the observation oints. Moreover, the expression can be modified to $((d_n - d_i)/(d_i + e))^k$ to take into consideration when ontouring admitted probable errors in the observations r sets of observations. In practice e is adjusted itera-ively by the program to suit particular data.

To calculate the value at a point, a surface of order J an be fitted by the familiar method of least squares to he n given observations with their associate weights. By selecting the origin of the horizontal axes to be the oint of calculation it is only necessary to solve the equired simultaneous equations partially, to obtain the arameter for zero power.

Whatever the weighting system, if the values of the bservations all lie on a surface of order J or less then he calculated surface will coincide with it exactly. In rder to define a surface of order J, $P_J = \frac{(J+1)(J+2)}{2}$ bservations with non-zero weights are required. How-ever, with irregularly spaced data there are many posi-ions on a map through which the contour could pass where a number of the n observations have zero weights, e.g., where extreme points lie on the circum-erence of a circle, centred on the point of calculation. Furthermore, since some points within the set may be co-linear even more points must be considered to ensure stability. Experience has shown that with regu-larly spaced data, the problem of a number of points having zero weight is more likely to occur (consider the observations at the points of a square). Practical numbers of points have been found to be 15 using first order solutions and 20 for second order.

To calculate the height of a central point using the foregoing method, it becomes questionable whether the more remote of the twenty points in the latter case are relevant. We are dealing here with natural data, and, while with mathematical data the behaviour of a function at remote points may give strong indications about its local behaviour, the fact that a knoll exists about a quarter of a mile away, tells us nothing about local terrain.

Finally, one must reach a compromise. The approximate number of points to be included in the height calculation must be decided for each type of data. The order of the surface to be fitted can then be decided, and n fixed. Where there is an accepted probable error in the observations e can be adjusted.

3. GENERATION OF CONTOURS

In order to utilize the method of calculation of point values discussed above, a special method of tracking contours has been devised which projects the contour in discrete steps. Consider Fig. 1 in which the last two projections completed for the contour are XY and YZ. The position of point C may be deter-mined by extrapolating the last step YZ distance d_1 to C. The values of A and B at displacements d_2 from C are then evaluated. The contour level interpolated between A and B to point P is then joined to Z. In this way the contour may be extended one step at a time. Clearly a suitable step length is determined by the irregularity of the surface to be contoured, e.g., in areas of large irregular height variation a much smaller step length is required to generate smooth con-tours than in level regions. In order therefore to com-bine smoothness of contours with speed optimization, the concept of variable step length has been introduced whereby, depending on how far point P is displaced from C, the next projected step remains the same as before, is doubled, or halved. In the event of point P

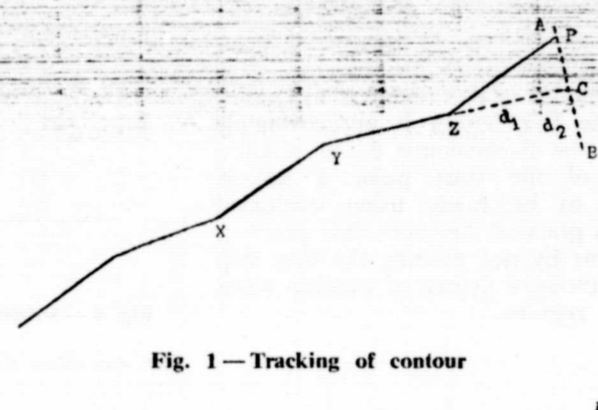

Fig. 1 — Tracking of contour

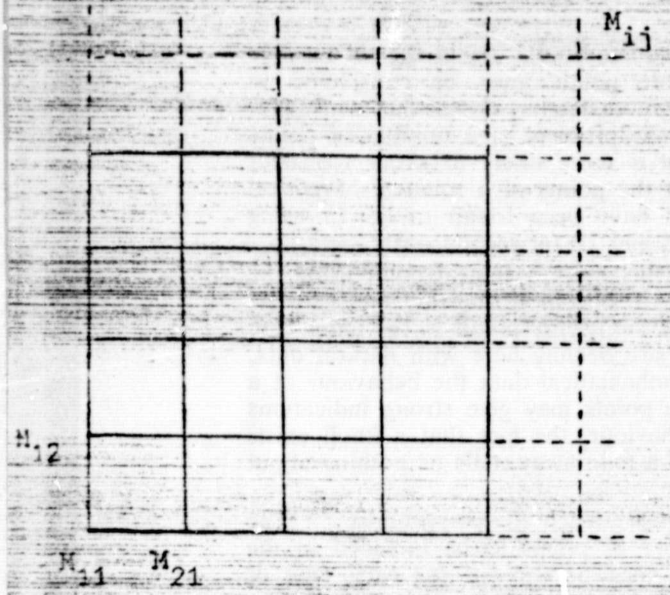

Fig. 2 — Mesh for tracking contours

lying outside A-B, the *previous* projected step ZC is halved and a further P determined. In the case of doubling, the maximum step length permitted is that of the link size between mesh intersections.

In order to begin the tracking procedure, the area to be contoured is subdivided into a uniform m x n mesh—Fig. 2. The values of the (m + 1) x (n + 1) mesh intersections ($M_{11}, M_{12} \ldots\ldots M_{ij} \ldots\ldots M_{m+1,n+1}$) are then evaluated. The levels of the maximum and minimum contours traversing each horizontal ($M_{ij} - M_{i+1,j}$) and vertical ($M_{ij} - M_{i,j+1}$), link joining adjacent mesh intersections are then stored along with the values of the minimum (1st) and maximum (nth) contour levels for the whole map. To begin contouring, these arrays holding the mesh link contour levels are searched until a minimum value coinciding with the first contour to be plotted is located. The intersection I of the link by the contour is then calculated by interpolation between the adjacent mesh intersections—Fig. 3.

The position of point C is determined at a displacement d_3 from I and A and B as before. Thus point P can be established and IP becomes the first step. In practice, linear interpolation between points A-B (Figs. 1, 3) has proved quite satisfactory for tracking contours. A problem arises, however, in the case of locating the start points between mesh intersections, since the curvature of the contour in this region is unknown. Furthermore, since the link length is approximately five times greater than the displacement d_2, to obtain a satisfactory position of the start point a second approximation ought to be made using evaluated values of the first. In practice, however, this problem is most easily overcome by not plotting the first step on the map, but permitting a degree of overlap when the tail of the contour rejoins.

As the contour is extended across the map surface the minimum array value of each link traversed is incremented, except when it also corresponds to the maximum value, in which case it is set to zero. The contour ceases when it cuts a link whose minimum value is not the level being contoured (e.g., the initial link incremented) or when a boundary is crossed.

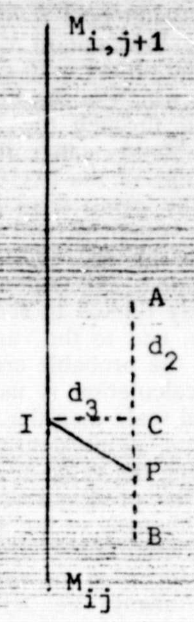

Fig. 3 — Commencement of tracking

When no further uncrossed links remain for that particular contour level, the next higher is begun and in this way all levels are completed.

The density of the m x n mesh is determined by the point density in the area to be contoured, and the size of the smallest closed contour to be shown, e.g., in contouring maps, containing 150 survey points of uniform spread, a mesh of 50 x 50 has proved sufficient, though a closed contour with axes less than one-fiftieth those of the map, not cutting a link, would not be located. A mesh size of 90 x 90 is used successfully on maps of similar size containing 1000 points.

The value of the step length d_1 and the displacements d_2 and d_3 have been determined by experience. In practice, the maximum permissible step-length is set at just below the minimum link size so that, apart from cutting corners, no more than one link will be traversed with one step. Displacements of one-fifth and one-twentieth respectively of the maximum step-length have proved suitable.

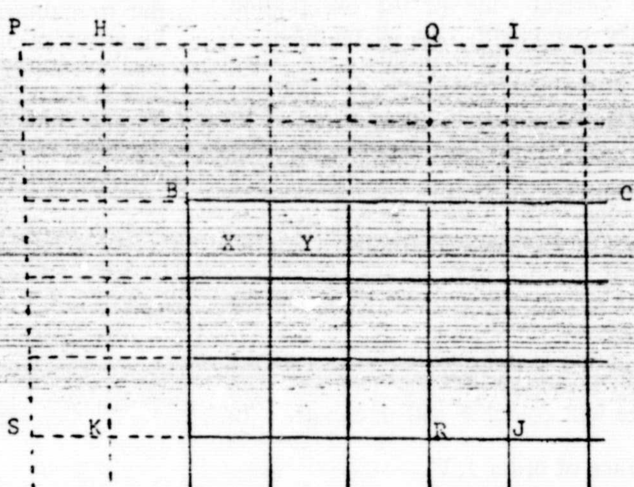

Fig. 4 — Subdivision of map area for location of observations

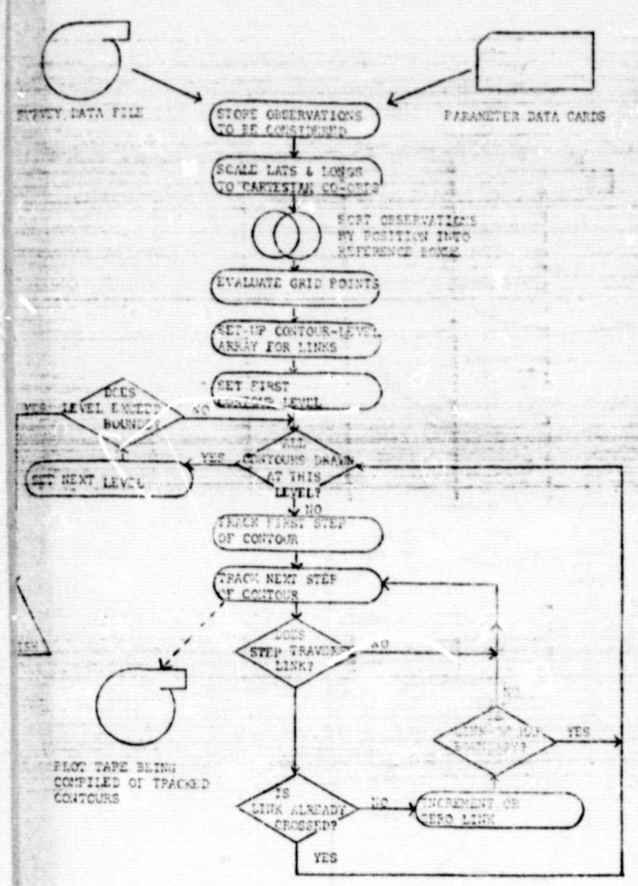

Figure 5

4. OPTIMIZING MACHINE TIME

Experience has shown that an operation which is expensive in terms of machine time is ordering the points in distance from the position of the evaluation being carried out. In a map area comprising 1000 survey observations, ordering for the many thousands of evaluations becomes an exhaustive task. For the techniques employed, generally only the nearest fifteen points are required. Therefore to limit the sorting involved, the map to be contoured is subdivided into a p x q array of boxes with the variables being selected to give a mean density of one observation per box. Furthermore, the observations to a depth of two boxes around the perimeter of the map are included to avoid discontinuities at map boundaries. For each evaluation the contents of 5 x 5 of the boxes surrounding the point are considered together and in this way rapid changes in the composition of the points as the contour moves across the surface of the map are avoided.

In Fig. 4, ABC defines one corner of the map to be contoured. Suppose the map to be contoured contains 374 points and has axes of 22 x 17 inches. Then by subdividing the area into 22 x 17 boxes, extended to 26 x 21 to include an adequate number of surrounding points, the 15 nearest points for an evaluation in box X, can be selected from the 25 observations (approximately) in PQRS. When the contour is

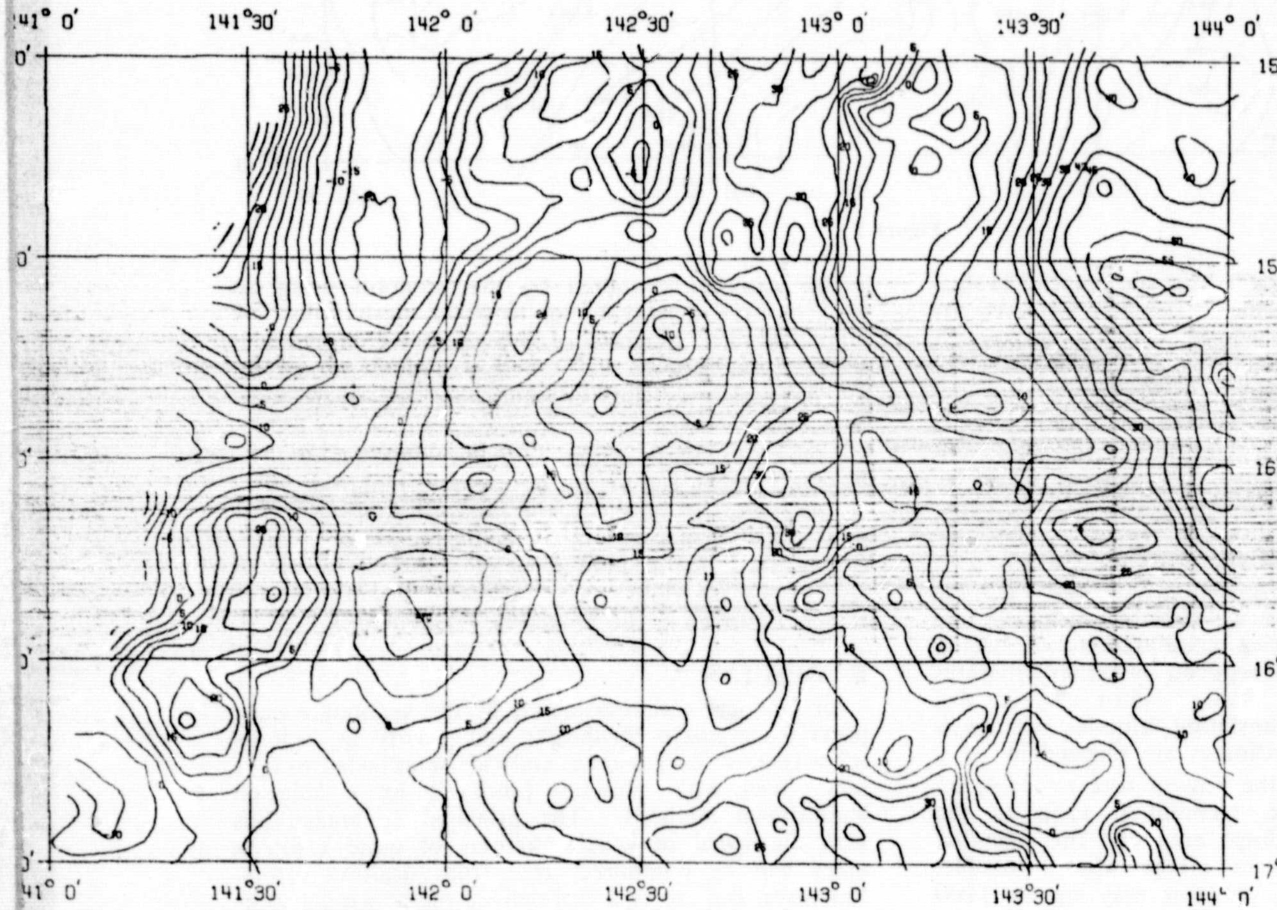

Figure 6

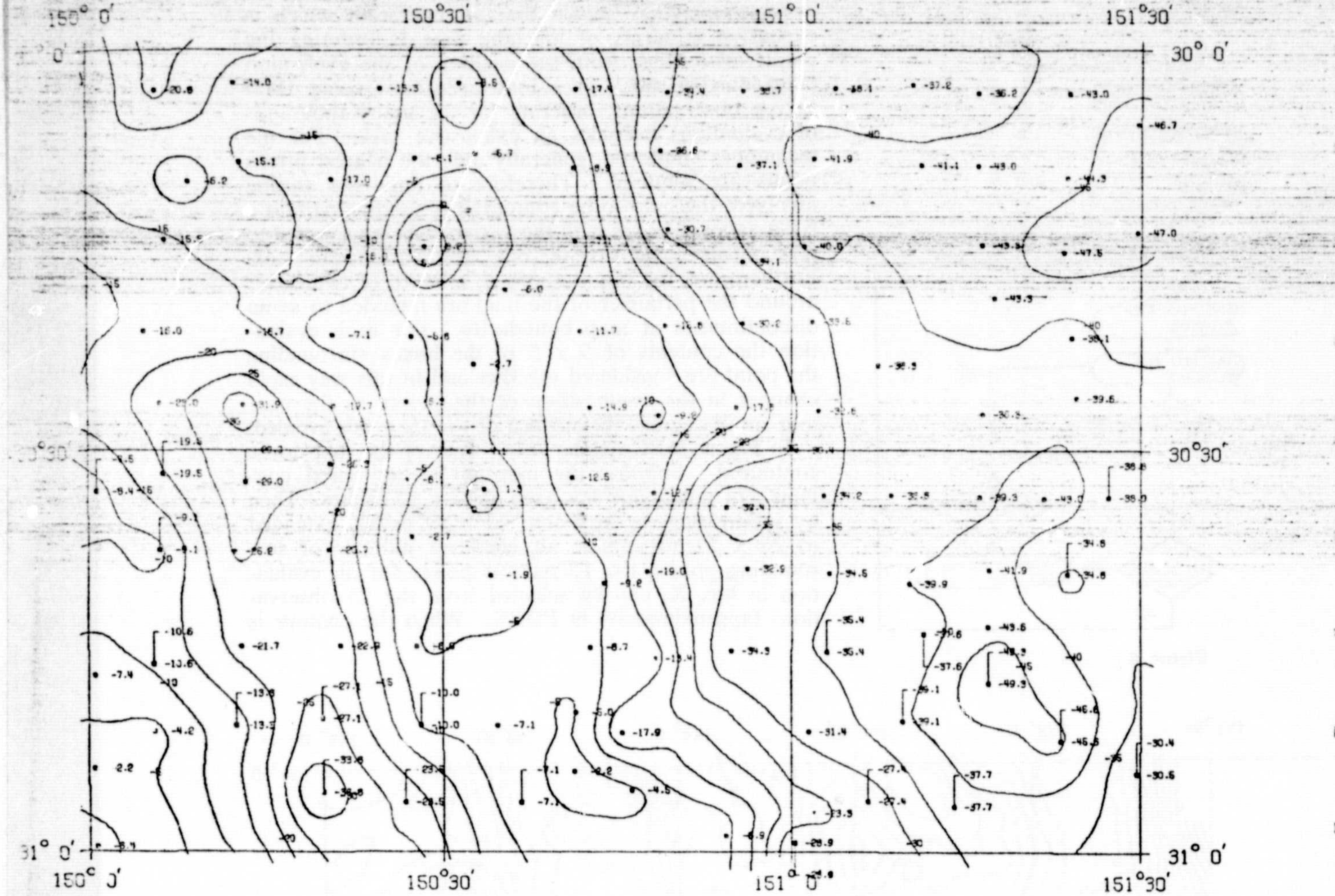

Figure 7

extended a number of steps so that the point of evaluation translates to box Y, the 25 boxes considered are defined by HIJK.

5. COMPUTER PROGRAM

The program is written in Fortran and has been created in the form of a number of modular subroutines so that it can be readily adapted to accept input in any of the usual modes (punched cards, paper tape or magnetic tape) and any type of co-ordinate data with associated values to be contoured.

Our usual input to the program has been via magnetic tape containing survey data as latitudes and longitudes, with one (or a combination) of height, gravity or magnetic values reduced by earlier programs (Bellamy and Lodwick, 1968). When used in this system subroutines for translating latitudes and longitudes into cartesian co-ordinates are plugged in.

In order to maximize the limited core available on the CDC3200 computer, techniques, such as the equivalencing of data storage area and the retention of information in character arrays where possible, have been incorporated. In this way up to 1100 points can be contoured by the program using an m x n mesh density of up to 8100 mesh links. A simplified flow diagram of the computer program is outlined in Fig. 5.

The parameter data communicated on each occasion is as follows:

1. the co-ordinates of the map area to be contoured
2. the number and values of contours required
3. the values of m and n, the mesh dimensions
4. the values of p and q, the box dimensions
5. the value n, the number of observations for calculating point values
6. the value of e, the weighting adjustment.

6. RESULTS

In practice, contours drawn by this technique have proved acceptable for height and gravity as well as other types of survey data, and can be adjusted to correlate well with contours produced by established hand-drawn methods. The principal advantage lies with the speed in which numbers of quite complex maps can be contoured, free from drafting errors. Moreover, the use of a well-defined mathematical tech-

que uniquely determines each particular map, while mple variation of parameters can produce different rsions of contours for special applications.

Experience has shown that the central processor ne is dependent on the complexity and irregularity the map surface, the number of contours to be otted, and the mesh size selected as suitable, and dependent of the scale of the map. In Fig. 7, conurs were drawn using a total of 230 points and a esh size of 56 x 44. This required less than seven inutes of computer time. A map such as that of ig. 6, in which 1000 points are contoured using a esh size of 105 x 70, takes about 20 minutes. ALCOMP plotter time is respectively 10 and 20 inutes.

. ACKNOWLEDGEMENTS

The authors would like to thank the Assistant irector (Geophysics), Bureau of Mineral Resources, r permission to use the data for contouring Fig. 6 nd Fig. 7. They would also like to acknowledge elpful criticism and suggestions received from colleagues at the Computer Centre and at the Bureau of Mineral Resources throughout the development of the program, and in particular the initial work done on the project by Mr. R. P. Brent and Mr. M. P. C. Legg.

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Branch Notes

CANBERRA

Since the last Journal was published, the following ddresses have been given.

May: "Feasibility is not enough." Mr. P. R. Masters, P.A. Management Consultants Pty. Limited.

April: The meeting was addressed by Dr. Grace Murray Hopper, Commander, United States Naval Reserve. Her topic was the development of programming languages in the United States Navy.

July: "The use of computers in meteorological research". Professor C. E. Wallington of the University of New South Wales.

NEW SOUTH WALES

Meetings held by the NSW branch since the last dition of this journal are:

April: Mr. Barry Smith of Compunet Limited, Canberra, who spoke on computer education and the computing profession.

May: Professor C. E. Wallington, the ACS lecturer for 1970. "The role of the computer in meteorological research." Also a joint meeting with the institute of radio and electrical engineers discussing the use of computers in engineering design.

June: Dr. Grace Hopper of Univac and the U.S. Navy discussed her career with computers since 1946 and offered some thoughts for the future. At another meeting this month, Dr. J. B. Hext of the University of Sydney discussed a basic course in the craft of programming.

Future Meetings

A program card has been produced for 1970 outlining meetings to be held by this branch during the rest of this year. These include:

Date	Speaker	Subject
Aug. 4:	Dr. R. W. Hamming, Bell Telephone Laboratories, New Jersey, U.S.A.	One man's view of computer science.
Aug. 11:	Dr. B. T. Allen, Manager, Operations Research, Caltex Oil (Aust.) Pty. Ltd.	Forecasting scheduling systems: rail tank car allocation to country depots.
Sept. 8:	Dr. M. W. White, Director, Australian Systems Development Institute	The role and facilities of a systems development institute.
Oct. 13:	Mr. D. Dyer, Superintendent, Systems Engineering, Australian Iron & Steel Pty. Ltd.	Simulation study — a case history.
Oct. 20:	Mr. J. E. Marr, Manager Computing, Sydney Stock Exchange	EDP systems at the Sydney stock exchange.
Oct. 26-27:	Prof. D. C. Evans, Director, Dept. Computer Science, University of Utah	A one day seminar and public meeting.
Nov. 17:	Mr. J. E. Dorn, Project Development Officer, Regional Computer Centre, N.C.R.	Fundamentals of operating systems.
Dec. 8:	Panel Discussion	Operating systems.

In addition, the annual feature speaker will be Mr. Max Dillon, Director and General Manager, Cables Group Metal Manufacturers Ltd. who will address a public meeting on 24th September. Also our annual conference at Terrigal has been retimed to take place during the long weekend, 6-8th November.

Register of Lecturers

Because of increasing requests from professional societies, the general public and the Department of

(Continued on Page 116)

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Record No. 1971/7

The Gravity Reductions, Storage and Retrieval System used by BMR

by

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RECORD 1971/7

THE GRAVITY REDUCTIONS, STORAGE AND RETRIEVAL SYSTEM USED BY BMR

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CONTENTS

ILLUSTRATIONS

SUMMARY

This Record outlines a suite of computer programmes which have been developed by the Bureau of Mineral Resources in conjunction with the Computer Research Section, Monash University for the automatic reduction of field gravity surveys. The techniques developed have proved in practice to be convenient and economic compared with hand computation. The programme system is designed to take gravity and heighting field results and ultimately produce Bouguer and free-air anomalies, storing the principle facts on magnetic tape in the process. The system as outlined is in use on the CDC 3600 computer, operated by CSIRO, Canberra.

1. INTRODUCTION

The gravity surveys carried out in Australia by the Bureau of Mineral Resources, Geology and Geophysics (BMR) are designed to establish control points for other surveys, to cover large areas for reconnaissance, or to investigate small areas in detail.

Since 1959, BMR has used helicopter transport for reconnaissance gravity surveying, and this has enabled an annual coverage of areas as large as New South Wales on a grid pattern with a seven-mile (11-kilometre) spacing of stations (Vale, 1962). Computer programmes have been developed to reduce the large amounts of data collected from these surveys to observed gravity, height, and free-air and Bouguer anomaly values for the stations, and to store the data in a form convenient for later retrieval and further processing. The programmes are written in Fortran and are used on CDC 3600 and 3200 computers. While the programmes were developed principally for the helicopter gravity surveys, they are sufficiently general to be applied to all types of gravity surveys and to all height surveys using barometers and a single base system.

With the introduction of the reductions system the Bureau has developed an eight-figure station numbering system, within which it is proposed that every gravity station in Australia will be uniquely numbered. The station number contains information on the first year of occupation and the type of survey in which it was observed (See Appendix A).

This Record presents the history of the development within BMR of electronic data processing (E.D.P.) computation, the methods used in carrying out gravity surveys and in computing or 'reducing' the data collected.

2. HISTORY OF E.D.P. DEVELOPMENT IN THE GRAVITY GROUP

The use of E.D.P. by BMR for the reduction of gravity data commenced in April 1961, when M.J. Goodspeed started running programmes from the BMR Melbourne office, on the Sydney University computer 'Silliac'. Most work at this stage was concerned with ice thickness problems, and very little was done towards automatic computation of Bouguer anomalies from field gravity and height readings. This process, usually known as reducing gravity data automatically was handicapped by the long time interval involved in transmission of programmes and data between Sydney and Melbourne.

When Mr Goodspeed resigned in January 1962, M.A. Reid took over programming, and between this time and his resignation had developed a number of height reduction programmes for Askania and Mechanism barometers, on the Sirius computer in Melbourne; these formed a basis for subsequent height reduction programmes.

On Mr Reid's resignation in January 1963, L.M. Hastie continued the work by writing a gravity reduction programme, a Bouguer anomaly programme, and a number of two-dimensional interpretational programmes. During 1963, other contributors to the two-dimensional interpretation suite of programmes included J.C. Dooley and R. Loy. A least-squares adjustment programme for barometric levelling was written by Dr C.J. Bellamy of Monash University

The programmes at this stage were being run at Monash University on the Sirius, and after Mr Hastie's resignation in June 1964, Dr Bellamy handled BMR gravity computing and transferred the programmes from Sirius to CDC 3200 at Monash.

In 1965, the gravity group moved to the Canberra offices, and from August 1965 when G.D. Lodwick joined the group the existing suite of programmes was being modified for use on the CDC 3600 at CSIRO in Canberra. By March 1967 when Mr Lodwick resigned, a useful set of gravity reduction programmes had emerged, written jointly by Dr Bellamy and Miss Austen of Monash University, and Mr Lodwick. That basic set of programmes, with some modifications, is described in this Record.

From March 1967 to May 1969, D.G. Townsend was engaged in reducing gravity data using the programmes mentioned. During this period, the changeover from CDC 3200 to CDC 3600 was finalised, the least-squares adjustment capacity in programme GRAVHTS was doubled, and an earlier programme COPYTAPE was eliminated by rewriting FIXSAF and subroutine FILMAN in GRAVHTS. Alterations made to the other programmes were such as to preserve the original control card structure.

3. NETWORK OF OBSERVATIONS

The pattern of flights* for any survey is designed to give repeat observations at intervals which are determined by the requirements for establishing gravity and barometer drift and ties between adjacent flights. The pattern forms a network in which total intervals (links) between the stations are adjusted using a least-square technique. For surveys carried out by helicopter, as far as possible the flight patterns are based on the "cell" method of gravity surveying, in which each 1:250,000 sheet area is divided into six rectangular cells (Hastie & Walker, 1962). A base station is sited centrally in each cell, and four loops are flown from the base to each of the tie stations at the corners, making the composite flight pattern appear like a set of four-petalled flowers with connected petal tips. Approximately eight intermediate stations are read on each loop, which spans some twenty-five miles between the base and the tie station andtakes about two hours to fly. For all surveys, base and tie stations form nodes in the network of observations, and the flight path joining two nodes is referred to as a link. In the case where an intermediate station in a flight has a known height or gravity value determined by a controlled survey it may also be considered as a node in the network.

It should be noted that the loops referred to, consist of a series of observations made at various stations (generally over a time interval of a few hours) starting and finishing at the same station for meter drift control. This is quite different from a <u>network</u> loop, which is often used to describe any closed path in the overall pattern of flights within one survey, and may extend over a large number of days.

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* A "Flight" in a helicopter gravity survey is defined as a drift-controlled series of observations with a station number sequence of the form a, b, c---a, which can be treated as a single block of data by the computer programme GRAVHTS (mentioned later).

4. LEAST-SQUARES ADJUSTMENT

There are two reasons for adjusting a network of observations by a least-squares technique. First, with large amounts of data it provides a convenient way of error detection at the node points. Second, best estimates, according to the least-squares criterion, can be obtained for the values at the base and tie points. Using the set of computer programmes, gross errors are detected by adjusting the network onto only one fixed node (control point) and examining the adjustments that have been made to the observations. When the gross errors have been detected and removed, the adjustment is repeated, utilizing all the control points, fixed at their given values.

The method of least-squares adjustment used enables the construction of a matrix of the coefficients in the normal equations, involving the unknown values of height or gravity at the free nodes (i.e. nodes which are not control points), directly from the observations and a list of fixed and free node stations.

Consider a network of n nodes numbered consecutively 1 to n with values h_i for the observed variable, be it height or gravity. The links joining the nodes are represented by the differences in values x_{ij} between nodes i and j. The condition equations for a least-squares adjustment, which minimizes the sums of the squares of errors in the differences x_{ij}, yield a set of p equations for p free nodes.

Let there be p free nodes and n-p fixed nodes, consider m_i links to the i^{th} free node from k other nodes, where m_i may be larger than k owing to multiple links. The condition equations are then given from:

$$x_{ij} = h_i - h_j$$

$$\therefore \quad m_i h_i - \sum_{j=1}^{m_i} h_j = \sum_{j=1}^{m_i} x_{ij} \qquad (1)$$

A second set of n-p equations can be written down for the n-p fixed nodes.

$$h_i = H_i \qquad (2)$$

Where H_i is the fixed value at the i^{th} fixed node. This yields a set of p normal equations which can be solved for the remaining h_i, the values at the free nodes. Having determined the h_i values the adjusted values for the links in the network X_{ij} ($=h_i-h_j$) and the standard deviation (S.D.) of the adjustments can be computed. The S.D. is used as an indication of the quality of the observations.

Once the values for the node points are established the values for the intermediate points in a flight are computed. For gravity surveys, the adjustments $(X_{ij}-x_{ij})$ are distributed equally between the L+1 intervals connecting the L intermediate stations and a pair of nodes. For height surveys the adjustments are distributed in proportion to the observed height differences of the L+1 intervals.

The relationship of the S.D. to the accuracy of individual stations in the network has not been theoretically determined, but it is obviously complex as it depends on both the geometry of the network and the distribution of control points throughout the network. In practice the S.D. when adjusting to one fixed node has been used as an indication of the quality of observations used in the network, that is, how well the links fit together. The programme GRAVHTS quotes the S.D. in its printout after least-squares adjustments have been made. For convenience, when this S.D. has been calculated for a network with the number of fixed points either one or zero, it is referred to as the internal standard deviation (I.S.D.). When adjusting to several fixed nodes the S.D. has been used as a measure of how well the network corresponds to a set of known values distributed throughout the area, and is referred to as the external standard deviation (E.S.D.). An experimental investigation has shown that provided about five percent of the observations are well distributed control stations to which the network is adjusted, the standard deviation of the errors in the final results is approximately equal to the standard deviation of the adjustments to one control station.

5. FIELD READINGS AND ACCURACY

A wide range of barometers is used for spot height measurements. The basic assumption is that the isobaric surface is a horizontal plane over the areas surveyed. The reductions are based on standard pressure lapse rate formulae, taking into consideration air temperature and humidity effects. In the field one barometer is read at the base station at about quarter-hour intervals in order to measure the atmospheric pressure diurnal. Comparison between field and base barometers at the beginning and end of the loop enables a correction to be applied for relative meter drift during a flight. Results that have been analysed indicate that in good conditions where height differences of the order of 500 feet (150 metres) are being measured using experienced observers in stable, slow-moving pressure conditions, the standard deviation of the errors in the computed heights are of the order of 7 feet (2 metres), while in bad conditions 10 feet (3 metres) is typical. Because of the relation between height and Bouguer anomaly, 7 feet represents approximately 0.5 milligals.

In the field, standard procedures are adopted for reading gravity. Drift control normally is established by reading at the beginning and end of the flight, and multiple drift control stations are handled by a mean slope technique. In general the standard error of the computed gravity values is of the order of 0.15 milligals. Station positioning can introduce up to 0.20 milligals error, since station latitude is used to determine Normal Gravity which enters the Bouguer anomaly calculation. Thus the error in the Bouguer anomaly at a station is approximately 0.6 milligals. The results are sufficiently accurate to be used for plotting contour maps at 2-milligal intervals for a station spacing of 4 miles (6.4 km), and 5-milligal intervals for a station spacing of 7 miles (11 km).

6. COMPUTER PROGRAMMES

The computer programmes provide the following procedures, which are illustrated in Plate 1:

1) Computation of gravity values from flight data.
2) Computation of height values from flight data.
3) The least-squares adjustment of networks constructed from machine- or hand-computed height or gravity data.
4) Computation of intermediate stations in the links in the networks once the node values have been determined.
5) Sorting of height or gravity data by station number, and the updating of a file for the area on a magnetic tape holding files for all previous areas computed (Survey Area File).
6) Editing of the Survey Area File including the addition of latitude and longitude data for each station.
7) Calculation of free-air and Bouguer anomalies for specified densities.

One programme contains all the procedures involved in creating an area file on magnetic tape with height and gravity values for each station. The input data on cards are arranged in blocks, one block containing height data or gravity data for one area. Control cards within each block specify the processing required, as the user may for example choose to use only the procedure for computing heights, or may follow it by a least-squares adjustment but not put the final results onto the Survey Area File. Should an error in the data within a block be detected, the computer terminates processing of that block and goes into the next.

Programme GRAVHTS

This programme contains the routine which assimilates hand-computed height and gravity flights, and prepares them for least-squares adjustments, by-passing the field data reductions stage. Moreover it controls the following subroutines:

(a) HTRDN - controls the following three subroutines which reduce the field barometer data to observed heights.

(b) DATAFEED - reads in a block of saturated water vapour pressure data, for later calculation of humidity corrections, and reads in the constants for the Askania-type microbarometers.

(c) DATAFIND - reads and prints the header card for each flight and locates the barometric constant data (if Askania).

(d) COMPUTE - calculates observed heights, according to Clark (1954, p. 454, equation 4). For each flight, the area, flight number, date, base and field meter numbers are printed out, followed by a list of station numbers beside which are printed height differences from base. Relative meter drift is printed out at the end of the flight. Programme design limits the number of stations in a flight to 50, and the number of base stations to 50.

(e) MNSLOPE - reads and checks LaCoste & Romberg gravity meter data, so that when a LaCoste meter is used in a particular flight the programme refers to this bank. Multiple drift controlled periods are evaluated by a mean slope technique. The printout consists of area, flight number, date, meter number, and scale factor followed by listed station numbers, beside each of which is printed the gravity difference from base, observation time, drift, and mean difference. The last is significant only in a flight with multiple drift control. It gives an indication of how well each individual drift period approximates the composite drift curve. Provision is made for up to 50 stations per flight.

(f) LEASTSQ - controls the following four subroutines which assemble and solve the matrix of normal equations for the network. The limits are 120 free nodes or 400 network links.

(g) SORT 2 (LIST, LENGTH)

(h) SORT 22 (KEY, DATA, LENGTH)

(i) SEARCH (ITEM, LIST, LENGTH, I) - are used for matrix assembly, and sorting reduced data in preparation for running the results onto the Survey Area File.

(j) FILEMAN - creates and updates magnetic tapes for blocks of data from LEASTSQ. At this stage the tape may contain station number, elevations and gravity, but space is left for later updating with latitudes and longitudes. The tape format is given by statement 1062. Provision is made for up to 2000 stations to be assimilated in each block.

Programme SAFILE

This programme contains two subroutines:

(a) PREPARE (J)

(b) ORDER (K) - these routines update latitude and longitude onto the Survey Area File by station number. Provision is made to accept 1000 stations in any one block. The format for the card input is given by statement 14 of Prepare (J). The programme is designed to accept banks of gravity flights already run through the GRAVHTS programme. Header and

END FLIGHT cards are neglected. The programme prints out a a listing of input stations, Survey Area File stations, latitudes, elevations, gravities.

Programme BA2

This programme takes the Survey Area File, locates a required area, and carries out Bouguer and free-air calculations for up to seven different densities. The printout consists of a listing of stations, latitudes, longitudes, elevations, observed gravities, free-air anomalies, and Bouguer anomalies.

Programme NAME

This is designed to put a BMR name on tape, immediately after the systems name. This is necessary before the first area is run onto the Survey Area File. It is of 80 characters, as a card image. Following the name is written the terminating statement ENDSAF.

Programme FIXSAF

This programme is designed to make amendments to the Survey Area File. Whole areas may be created or deleted, stations removed or added to particular areas, or modifications carried out to the value at particular stations. The limit is 1000 stations to be updated or created under any one area title.

Programme CREATE

This programme combines programmes NAME and FIXSAF and is not limited to 1000 stations as in FIXSAF, as the SORT subroutine is not invoked and stations are put onto tape (which may or may not have a SAF title) in the card order presented.

7. INSTRUCTIONS ON RECORDING FIELD SHEETS

Because data cards are punched directly from the observation sheets it is essential that observations are written clearly and carefully. Moreover, since reductions are usually carried out by people not engaged in the actual field work, ample use should be made of the remarks columns.

Sample barometer data sheets are set out in Appendix B. A typical day's work would consist of one set of base data followed by four flights. At the head of each sheet are boxes in which to insert observer's name, survey number, and day number. These are for identification only and are not punched up for the computer. The header card consists of an area name (8 alpha-numeric), traverse name (3 alpha-numeric), date (6 alpha-numeric) field meter (7 alpha-numeric) and base meter (7 alpha-numeric). The date consists of two figures for each of day, month and year. In the last square in the boxes for field and base meters is placed a letter indicating the type of barometer used: A = Askania, M = millibar reading type, Z = tor (mm Hg) reading type. The meter numbers must be inserted correctly for the Askanias, since data for these barometers will be provided from an inserted bank.

When recording base data the station number <u>must</u> be left blank. Time is recorded to the nearest minute using a twenty-four hour clock, and barometer readings are written with 4 figures before and 2 after the decimal. For the past surveys the column marked CORR'N is used to indicate Askania instrument temperatures; in present surveys where these are no longer used the programmes may be modified to apply corrections to field observations, e.g. for the tilt of the isobaric plane. The segment is relevant only to Askania, the two figures placed immediately after the wet temperature. All temperatures are recorded in centigrade to the nearest tenth of a degree. Should more than one sheet be required for the base data, the header card is not filled out again.

For the first flight after the base data the header card data <u>must</u> be ruled out. The relevant data for this flight are filled in on the base header card. For all subsequent flights referring to that base, the header card <u>is</u> filled out. The station number consists of eight figures (4 before and 4 after the decimal). Other readings are recorded as for the base. No dry and wet temperatures are included in field observations. At the completion of a flight ENDFLIGHT printed indicates to the punch operator to insert the appropriate card.

A sample gravity sheet is set out in Appendix C. In general the gravity is filled in like the barometer field data, with a few exceptions. First the letter for the field meter may be L, otherwise blank. L indicates a LaCoste meter, so that the scale factor will be blank. The meter number must be inserted accurately so that the programme will refer to the appropriate data. For other meters the scale factor is inserted with 3 figures before and 5 after the decimal. Second, the programme ignores instrument temperature. The effect of temperature on readings is at present neglected, but may be allowed for at a later date. Finally, latitudes and longitudes are inserted in degrees, minutes and tenths of minutes.

8. INSTRUCTIONS ON PROGRAMME USE

Card decks exist for the programmes. Systems cards (JOB, RUN, ENDFILE) are placed before and after the programmes and at the end of the data deck (for use of these consult the CDC 3600 reference manual).

Programme GRAVHTS

A complete reduction of an area containing height and gravity data using GRAVHTS will terminate with storage of the area on the Survey Area File. This will consist of the area name followed by, in ascending station order a BCD listing of station, latitude, longitude, elevation, gravity. At this stage latitude and longitude are blank. The deck for such a reduction is assembled in the following number.

1. JOB card
2. GRAVHTS programme deck
3. RUN card
4. GRAVITY 1/1 card
5. AREA card
6. LACOSTE deck
7. ENDMETER card
8. GRAVITY deck
9. ENDGRAVS card
10. LSA card
11. ADJUSTMENT card
12. NODE deck
13. ENDNODES card
14. CREATE card
15. SURVEY AREA FILE card
16. AREA card
17. HEIGHTS 1/1 card
18. AREA card
19. SATURATED WATER VAPOUR PRESSURE deck
20. ASKANIA deck
21. ENDMETER card
22. HEIGHT deck
23. ENDHGHTS card
24. LSA card
25. ADJUSTMENT card
26. NODE deck
27. ENDNODES card
28. UPDATE card
29. SURVEY AREA FILE card
30. AREA card
31. END card

Cards 1 and 3 are systems cards. The HEIGHT AND GRAVITY cards have these letters respectively punched in column 11. In columns 12, 13 is punched the number of areas to be adjusted together, in columns 9,10 the sequential number of the particular area e.g. 1/2, 2/2 etc. (usually this facility is not used, in which case 1/1 is punched in. If it were to be

used, the LSA card would be placed behind the ENDHGHTS card of the last HEIGHT deck, so that the relevant separate height areas would be least-squares adjusted as one).

The AREA card has a free field of 80 characters. The saturated water vapour pressure deck, consists of 60 cards numbered -10 to 49 in columns 4 and 5, each number corresponding to the temperature (degrees centigrade). Following this on each card in format 10F5.3 is the SWVP data, one entry for each tenth degree. These data are available in the Smithsonian Physical Tables (1943 reprint), Tables 207 and 208.

The ASKANIA METER deck has one card for each meter. First the meter number is punched in columns 1 to 6, then the relevant data for measuring ranges 10 to 17 are punched in format 8F6.2 from column 7. The values of m and c follow in format 2F6.4 from column 55, the number of divisions per range, F6.4 from column 76. Up to 20 meters can be inserted, terminated by an ENDMETER card, punched from column 73.

For gravity the LACOSTE METER deck can contain up to 10 meters, data from which are punched as follows. The first card contains the meter number punched in format A6 from column 1. The next seven cards, numbered consecutively 0 to 6, in format 5X, 13 from column 1, contain the values in milligals from various readings. On card 0, in format 10F7.2 from column 9 are punched the values for counter readings 000 to 900 respectively. Card 1 contains 1000 to 1900 etc. so that the last value on card 6 will be for 6900. The conversion factors for the intervals are punched in format 10F7.5 from column 9 on cards 10 to 16, starting with factor at 000 and finishing with that for 6900.

The HEIGHTS and GRAVITY decks consist of data in flights, each terminated by ENDHGHTS and ENDGRAVS card respectively, punched from column 73. To carry out a least-squares adjustment, LSA is punched in the first three columns of the next card. The ADJUSTMENT card follows with the number of areas to be adjusted together punched in columns 1 and 2, the number of all nodes in columns 3 to 5, and the number of fixed nodes in columns 6 to 8. In columns 9 to 16 is punched the mean datum to be used when the adjustment is done - format F8.1. In columns 17-21, 22-26, the maximum acceptable standard deviation and adjustment respectively are printed - format 2F5.2. (Note here that for gravity the datum for the programme is already 978,000.0 milligals). This card is followed by the NODE deck, consisting of all node stations the numbers of which are punched in the first eight columns, one to a card, followed by the numbers of the fixed nodes (repeated) with their values - format F8.4, F8.2. The deck is terminated by a card with ENDNODES punched in the first eight columns.

The following control cards create the file for an area on the SURVEY AREA FILE: first a card with CREATE punched in the first 6 columns, second a card with the SURVEY AREA FILE NAME, which becomes the magnetic tape title, and finally the AREA card. The last two cards are free field - 80 characters. These three cards are placed after ENDNODES causing a new area to be created and the SAF rewound.

The control cards necessary to update the file are as for CREATE except that first card has UPDATE punched in the first 6 columns. Height or gravity results can be updated or created, but 'update' must follow some previous establishment of data for that area being updated. Note that the SAF file is copied onto Logical Unit 2, to start with CREATE. After UPDATE it will be on LU3. The last data card of any deck must be one with END punched in the first 3 columns. Flights of hand-calculated data can be assimilated by the programme; for card 6, RED HTS is substituted for HEIGHTS; for card 20, RED GRAV is substituted for GRAVITY. The height or gravity difference from the first station in the flight (considered as zero) is punched in behind the station number, format F8.2, F8.4, for each card. The 1/2, 2/2 facility enables areas containing both hand- and machine-calculated flights to be least-squares adjusted as one.

Programme SAFILE

The layout of this deck is as follows:

1. JOB card
2. SAFILE programme deck
3. RUN card
4. SURVEY AREA FILE NAME card
5. AREA card
6. LATITUDE, LONGITUDE deck
7. ENDLATS card
8. ENDSAF card

The SAF NAME and AREA cards are as before. In the LATITUDE, LONGITUDE deck, header cards and ENDFLIGHT cards are ignored. The ENDLATS card (punched in columns 1-7) follows the deck. If another area is to be updated a new AREA card follows, then the deck etc. The final card is ENDSAF punched in the first 6 columns. The SAF tape is equipped 4 = magnetic tape (read only), 3 = magnetic tape (write enable), the updated output is 2 = magnetic tape (write enable). This programme accommodates multiple updating within the one run.

Programme BA2

The layout of the deck is as follows:

1. JOB card
2. BA2 programme deck
3. RUN card
4. SURVEY AREA FILE NAME card
5. AREA card
6. DENSITY card
7. BLANK card

The SAF NAME and AREA cards are as before. Provision is made for up to 7 densities to be calculated, punched on the DENSITY card in format 7F5.2. The SAF tape is equipped to logical unit 40 = magnetic tape (read only). Bouguer anomalies for more than one area on the SAF tape

can be calculated in the one run by inserting the relevant AREA and DENSITY cards before the blank card.

Programme NAME

The layout for this deck is as follows:

1. JOB card
2. NAME programme deck
3. RUN card
4. SURVEY AREA FILE NAME card

The SAF NAME card consists of a single card, 80 characters, free field. A tape is equipped 1 = magnetic tape (write enable).

Programme FIXSAF

The layout for this deck is as follows:

1. JOB card
2. FIXSAF programme deck
3. RUN card
4. C/CREATE card
5. DATA deck
6. END card
7. SURVEY AREA FILE NAME card
8. AREA card

The C/CREATE card is punched from column 1. Cards in the DATA deck may contain the following information - station number (columns 1-10), latitude (15-20), longitude (24-30), heights values (32-41), gravity values (42-51). Latitude and longitude are presented in degrees, minutes and hundreths of minutes. Heights and gravity values are punched in format F10.2. Any of these (besides the station number) may be left blank. A complete new area is added with the C/CREATE facility.

To update a particular area C/UPDATE, punched from column 1, is inserted for C/CREATE. The data card layout is as above except that a station number with D punched in column 11 will be completely deleted from the file. Blanks or zero fields on cards will cause data held in these positions on tape to be unchanged. To delete a whole area from the tape, the DATA deck and END cards are left out and the control card is C/DELETE.

The SAF tape is equipped 1 = magnetic tape (read only), the updated output is 2 = magnetic tape (read-write), B = Magnetic tape (read-write).

Any number of UPDATEs and CREATEs may follow each other with sections 4-8 (above) repeated consecutively.

9. REFERENCES

CLARK, D., 1954 - Plane and Geodetic Surveying, Fourth Edition, Vol. 2.

HASTIE, L.M. and WALKER, D.G., 1962 - Two methods of gravity traversing with helicopters. Bur. Min. Resour. Aust. Rec. 1962/134 (unpubl.).

VALE K.R., 1962 - Reconnaissance Gravity Surveys, Using Helicopter for Oil Search in Australia. Bur. Min. Resour. Aust. Rec. 1962/130 (unpubl.).

APPENDIX A

STATION NUMBERING FOR GRAVITY SURVEYS

(developed by Mr L.M. Hastie)

1. In order to integrate an Australia-wide network of gravity stations the system of station numbering adopted must provide a unique identifying number for each station. It is also considered desirable that as much information as possible about the station be encoded in its number. In view of these requirements the Bureau of Mineral Resources had adopted as its standard an eight-figure station number, having four figures before a decimal point and four figures after. The integral part contains the year of the survey, and the identifying serial number of the survey, while the fractional part specifies the individual station; e.g. the first station occupied in the first survey of 1965 would have the number 6501.0001.

2. It is hoped that private companies engaged on gravity surveys throughout Australia will adopt this numbering system. Particular survey numbers will be designated immediately upon request to the Gravity Section, Bureau of Mineral Resources, Canberra. However, it is essential that the eight-figure numbering system be used when reductions are carried out with the BMR computer programmes.

3. The integral part of the survey number (for example in 1965) is grouped into the following four categories:

BMR pendulum surveys	6599
BMR gravity control surveys	6590 to 6598
Private company gravity surveys	6530 to 6589
BMR gravity surveys	6500 to 6529

For the purposes of this discussion a 'control survey' is defined as a survey using multiple gravity meters.

4. In any survey, numbers .0000 to .8999 are available for general gravity stations established, while .9000 to .0000 are reserved for control stations. Those control stations are subdivided as follows:

Absolute gravity stations	9990 to .9999
Primary gravity control stations (Mount Gambier Pendulum 5099.9907).	.9900 to .9989
Secondary control stations (Hamilton Isogal 6491.9002) and tertiary control stations (Tumut cell centre 6606.9062)	.9000 to .9899

The only control stations which can be established in the course of an ordinary gravity survey are tertiary control stations; all other classes of control stations require a multi-meter control survey.

5. In the course of a gravity control survey, two categories of station, other than those mentioned above, may be established - excentre stations and calibration stations.

Excentre stations should be given a number in the range .0000 to .8999, and should have their last 2 digits identical to those of the absolute station, national base or primary gravity station, to which they refer, the first and second digits being used to distinguish between various excentres established by the one survey; e.g. excentres to primary control station 6591.9925 would be 6591.0125, 6091.0125, 6793.0125, 6793.0225. Excentres of secondary base stations should have the last 3 digits identical with those of the secondary base to which they refer.

Calibration stations should be similarly numbered, except that they will refer only to primary control stations or to absolute or national base stations.

6. When entered on a map, the fractional part of the number should be inscribed beside the station symbol. This will be preceded by a letter representing the integral part, and a key to the relationship should be provided in the legend of the map.

7. If any established station is reoccupied, either in the same survey or in a subsequent survey, it should retain the number given upon establishment.

APPENDIX B

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OBSERVER	SURVEY Nº	DAY		
P. MILSØM	6702	002	~~HEIGHT~~ BASE	H 24139

AREA	TRAV	DATE	FIELD METER	BASE METER
MILNEBAY	HS2	060367	597M	317M

Geophysical Branch,
Bureau of Mineral Resources
Geology and Geophysics

STATION	TIME	READING	CORR'N	AIR TEMP °C DRY	WET	REMARKS
	0805	099797		27	25	
	0845	099825		28	25	
	0905	099839		28	25	
	0925	099855		29	21	
	1015	099814		29	26	
	1035	099795		29	26	
	1055	099789		29	26	
	1115	099773		29	27	
	1135	099734		29	26	
	1155	099677		30	27	
	1215	099648		30	27	
	1235	099624		30	26	
	1255	099596		30	27	
	1356	099516		31	28	
						sheet 1 of 1

OBSERVER	SURVEY Nº	DAY		
JSMILSOM	6701	002	HEIGHT	H 24140

AREA	TRAV	DATE	FIELD METER	BASE METER
~~MILNEBAY~~	~~HS2~~	~~060367~~	~~579M~~	~~317M~~

Geophysical Branch,
Bureau of Mineral Resources
Geology and Geophysics

STATION	TIME	READING	CORR'N	AIR TEMP °C DRY	WET	REMARKS
67010001	0804	100331				
67010009	0903	100554				
67010010	1021	100227				
67010011	1030	100482				
67010012	1045	100492				
67010001	1356	100041				
						END FLGHT.

APPENDIX C

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OBSERVER	SURVEY №	DAY
TOWNSEND	681.5	

GRAVITY

H 17026

Geophysical Branch, Bureau of Mineral Resources Geology and Geophysics

AREA	TRAV	DATE	FIELD METER	SCALE FACTOR
GOSBLUFF	013	24.07.69	1.011	

STATION	TIME	READING	INSTR TEMP °C	LATITUDE	LONGITUDE	REMARKS
6.8.1.5.1.2.1.6	0.9.5.0	2.2.6.3.8.4	5.2.			
6.8.1.5.1.3.1.6	1.0.0.0	2.2.6.2.9.6	5.2.			
6.8.1.5.1.3.1.5	1.0.1.0	2.2.6.1.8.8	5.2.			
6.8.1.5.1.3.1.4	1.0.1.8	2.2.6.2.2.9	5.2.			
6.8.1.5.1.3.1.3	1.0.2.6	2.2.6.0.7.4	5.2.			
6.8.1.5.1.3.1.2	1.0.4.3	2.2.6.1.6.5	5.2.			
6.8.1.5.1.3.1.1	1.0.5.4	2.2.6.1.3.4	5.2.			
6.8.1.5.1.3.1.0	1.1.1.7	2.2.6.1.3.9	5.2.			
6.8.1.5.1.3.0.9	1.1.2.3	2.2.6.0.8.7	5.2.			
6.8.1.5.1.2.0.6	1.1.3.8	2.2.6.3.8.1	5.2.			
6.8.1.5.0.1.3.3	1.1.4.8	2.2.6.0.3.3	5.2.			
6.8.1.5.1.2.1.6	1.1.5.7	2.2.6.3.8.4	5.2.			
						END FLGHT

1 of 1

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APPENDIX D

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      PROGRAM GRAVHTS
CXXXXXPROGRAM TO CARRY OUT  GRAVITY AND HEIGHT CALCULATIONS INCLUDING
CXXXXXTHE LEAST SQUARES ADJUSTMENT OF THE NETWORK IF SPECIFIELD,
CXXXXXSEVERAL PROCEDURES ARE AVAILABLE AND ARE SPECIFIED BY CONTROL
CXXXXXCARDS,THESE ARE FOR HEIGHT REDUCTIONS,GRAVITY REDUCTION, LEAST SQUARES
CXXXXXADJUSTMENT AND THE CREATION OR UPDATING OF FILES (SAF SURVEY AREA
CXXXXXFILES ON MAGNETIC TAPE.)
CXXXXXTHE PROGRAM IS OVERLAYED TO RUN ON A 16K 3200 BUT NOT FOR A 32K
CXXXXX3200 OR 3600.
      COMMON IERROR,IN,IOUT,IRES,INDGH,DUMMY(2000),RESULT(2000),ISTNS(2,
     12000)
      DIMENSION IAREACD(20)
      REWIND 37
      IN=1
      IOUT=2
   14 READ(60,1000) IDENT1,IDENT2,NO,MO
 1000 FORMAT(2A4,I2,X,I2)
      IF(IDENT1.EQ.4HHEIG)1,2
    2 IF(IDENT1.EQ. 4HGRAV)3,4
    4 IF(IDENT1.EQ.3HLSA) 5,6
    6 IF(IDENT1.EQ.4HUPDA)7,8
    8 IF(IDENT1. EQ.4HCREA)9,10
   10 IF(IDENT1.EQ.4HRED .AND.IDENT2.EQ.4HGRAV)101,102
  102 IF(IDENT1.EQ.4HRED .AND.IDENT2.EQ.4HHTS )103,110
  110 IF(IDENT1.EQ.3HEND)11,12
   12 WRITE(61,1002) IDENT1,IDENT2,NO
 1002 FORMAT(X,37HILLEGAL CONTROL CARD,COLS 1 TO 8 ARE ,2A4,I2)
C     CARRY ON AND SEARCH FOR NEXT HEIGHT OR GRAVITY CARD WITH 1 IN COL 10
      GO TO 13
C**** FOR LEAST SQUARES ADJUSTMENT OF HAND COMPUTED GRAVITY AND HEIGHTS
C**** SET INDGH THEN COPY DATA TO LU 37 IN REQUIRED FORMAT
  101 INDGH=3RGRA
      READ(60,1003)IAREACD
      WRITE(37,1003)IAREACD
      WRITE(61,1101)IAREACD
 1101 FORMAT(1H1,49HREDUCED GRAVITY DATA FOR LEAST SQUARES ADJUSTMENT./,
     121HAREA IDENTIFICATION  , 1H*,20A4,1H*)
      GO TO 130
  103 READ(60,1003)IAREACD
      WRITE(37,1003)IAREACD
      WRITE(61,1103)IAREACD
 1103 FORMAT(1H1,49HREDUCED HEIGHT DATA FOR LEAST SQUARES ADJUSTMENT./,
     121HAREA IDENTIFICATION  ,1H*,20A4,1H*)
      INDGH=3RHTS
  130 READ(60,1003)IAREACD
      IF(IAREACD(19).EQ.4HENDG.OR.IAREACD(19).EQ.4HENDH)131,132
  131 ENDFILE 37
      IF(MO.EQ.NO)138,14
  138 REWIND 37
      GO TO 14
  132 KT=1
      WRITE(61,1138)IAREACD
 1138 FORMAT(5(/),X,20A4,/)
  135 READ(60,1132)ISTNS(1,KT),ISTNS(2,KT),RESULT(KT),IPOP
 1132 FORMAT(2R4,F8.2,56X,R4)
      WRITE(61,1139)ISTNS(1,KT),ISTNS(2,KT),RESULT(KT)
```

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```
 1139 FORMAT(X,R4,1H.,R4,2X,F8.2)
      IF(IPOP.EQ.4RENDF)133,134
  134 KT=KT+1
      GO TO 135
  133 L=KT-1
      WRITE(37,1134)(IAREACD(I),I=1,8),L
 1134 FORMAT(8R4,I3)
      WRITE(37,1133)(ISTNS(1,I),ISTNS(2,I),RESULT(I),I=1,L)
 1133 FORMAT(6(R4,1H.,R4,F8.2))
      GO TO 130
    1 READ(60,1003) IAREACD
      WRITE(37,1003)IAREACD
 1003 FORMAT(20A4)
      WRITE(61,1005) IAREACD
 1005 FORMAT(1H1,11HHEIGHT DATA,//,X,21HAREA IDENTIFICATION  ,1H*,20A4,1
     1H*)
      INDGH=3RHTS
      CALL HIRON
      ENDFILE 37
      IF(IERROR.EQ.-1)13,25
    3 READ(60,1003) IAREACD
      WRITE(37,1003)IAREACD
      WRITE(61,1004) IAREACD
 1004 FORMAT(1H1,12HGRAVITY DATA,//,X,21HAREA IDENTIFICATION  ,1H*,20A4,
     11H*)
      INDGH=3RGRA
      CALL MVSLOPE
      ENDFILE 37
      IF(IERROR.EQ.-1)13,25
   25 IF(MO.EQ.MD)27,14
   27 REWIND 37
      GO TO 14
    5 CALL LEASTSQ
      REWIND 37
      IF(IERROR.EQ.-1)33,14
    9 IERROR=2
      CALL FILEMAN
      IN=2
      IOUT=3
      GO TO 14
    7 IERROR=1
      CALL FILEMAN
      GO TO 14
C**** SEARCH FOR NEXT HEIGHT OR GRAVITY CARD WHICH IS FIRST OF AN AREA
   13 REWIND 37
   33 READ(60,1006)IDENT1,IDENT2, NO,MO
 1006 FORMAT(2A4,R2,X,R2)
      IF(IDENT1.EQ.4HEND )11,17
   17 IF(IDENT1.EQ.4HHEIG.AND.NO.EQ.2R 1)1,18
   18 IF(IDENT1.EQ.4HGRAV.AND.NO.EQ.2R 1)3,33
   11 STOP
      END
```

```
      SUBROUTINE HTRDN
C***  SUBPROGRAM CONTROLLING SUBROUTINES WHICH REDUCE BASIC HEIGHT DATA
      COMMON IERROR,IN,IOUT,IRES,INDGH,SEG(20,8),MA(20),CA(20),SWVP(700)
     1,VA(20),JA,BARNO(20),APPHT,APPLAT,APPMPRES,I,J,ABC,DEF
      REAL MA,VA
      INTEGER BARNO,ABC,DEF
      IERROR=0
      CALL DATAFEED
      IF(IERROR.EQ.-1)2,1
    1 IEND=0
      CALL DATAFIND(IEND)
      IF(IEND.EQ.-1)2,3
    3 CALL COMPUTE
      GO TO 1
    2 RETURN
      END
```

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```
      SUBROUTINE DATAFEED
C*** SUBROUTINE TO FEED IN CONSTANT BAROMETER DATA
      COMMON IERROR,IN,IOUT,IRES,INDGH,SEG(20,8),MA(20),CA(20),SWVP(700)
     1,NA(20),JA,BARNO(20),APPHT,APPLAT,APPMPRES,I,J,ABC,DEF
      INTEGER TEMP,BARNO  ,ABC,DEF
      REAL MA,NA
C*** READ IN SATURATED WATER VAPOUR PRESSURE DATA FOR CALCULATING ATMOSPHER
C*** CORRECTIONS LATER
      DO1L=1,70
      NN=10*L
      NNN=NN-9
      READ 99,TEMP,(SWVP(K),K=NNN,NN)
   99 FORMAT (I5,10F5.3)
      IQ =  -11+L
      IF(TEMP.EQ.IQ)8,9
    8 IF(IQ.EQ.47)2,1
    1 CONTINUE
    9 PRINT 98,IQ
   98 FORMAT (32H WRONG POSITION DATA CARD NUMBER,I5)
      IERROR=-1
      RETURN
C*** READ IN CONSTANTS FOR REQUIRED ASKANIA MICROBAROMETERS
    2 DO3 JA=1,20
      READ 97,BARNO(JA),(SEG(JA,IA),IA=1,8),MA(JA),CA(JA),NA(JA),IPAP
   97 FORMAT(A6,8F6.2,F6.6,F6.5,F6.2,A4)
      IF (IPAP.EQ.4HENDM)4,3
    3 CONTINUE
      JA=20
    4 RETURN
      END
```

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```
      SUBROUTINE DATAFIND(IEND)
      DIMENSION AREA(2)
      COMMON IERROR,IN,IOUT,IRES,INDGH,SEG(20,8),MA(20),CA(20),SWVP(700)
     1,NA(20),JA,BARNO(20),APPHT,
     1 APPLAT,APPMPRES,I,J,ABC,DEF,AREA,IFLIGHT,IDAY,MONTH,IYEAR,FBARNO,
     1BBARNO
      INTEGER BARNO,FBARNO,BBARNO,ABC,DEF,AREA
      REAL MA,NA
      APPLAT =  24. $  APPHT = 1500.$  APPMPRES = 730.
C*** READ IN AREA,DATE,INSTRUMENT DATA FOR THE PARTICULAR FLIGHT
    4 READ 96,AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,FBARNO,ABC,BBARNO
     1,DEF,IPIP
   96 FORMAT(2A4,A3,3I2,A6,A1,A6,A1,41X,A4)
C*** CHECK WHETHER HEIGHT DATA COMPLETED
      IF( IPIP   .EQ.4HENDH)1,2
    1 IEND=-1
      RETURN
    2 PRINT 99,AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,FBARNO,ABC,
     1BBARNO,DEF
   99 FORMAT(///,1X,2A4,3X,7HFLIGHT ,A3,3X,3I3,3X,11HFIELD METER ,A6,A1,
     13X,10HBASE METER,A6,A1,/)
      APPLAT =APPLAT* 3.1416/180.
C*** CHECK WHETHER FIELD BAROMETER MECHANISM OR ASKANIA
      IF(ABC.EQ.1HM.OR.ABC.EQ.1HZ) 5,20
   20 DO 14 I=1,20
      IF (FBARNO.EQ.BARNO(I))5,7
    7 IF(I.EQ.JA-1)6,14
   14 CONTINUE
      I=20
    6 PRINT 95
   95 FORMAT(X,50(1H*),25H FIELD BAROMETER NOT FOUND)
      IERROR=-1
      GO TO 22
    5 IF(DEF.EQ.1HM.OR.DEF.EQ.1HZ)11,21
   21 DO 10 J=1,20
      IF(BBARNO.EQ. BARNO(J))11,12
   12 IF(J.EQ.JA-1)13,10
   10 CONTINUE
      J=20
   13 PRINT 94
   94 FORMAT(X,50(1H*),25H BASE BAROMETER NOT FOUND)
      IERROR=-1
   22 READ 93,IPOP
   93 FORMAT (72X,A4)
      IF (IPOP.EQ.4HENDF )4,22
   11 RETURN
      END
```

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```
      SUBROUTINE COMPUTE
      COMMON IERROR,IN,IOUT,IRES,INDGH,SEG(20,8),MA(20),CA(20),SWVP(700)
     1,NA(20),JA,BARNO(20),APPHT,
     1 APPLAT,APPMPRES,I,J,ABC,DEF,AREA,IFLIGHT,IDAY,MONTH,IYEAR,FBARNO,
     1RBARNO
      DIMENSION AREA(2)
      INTEGER AREA
      DIMENSION STATION(50),DRY(50),WET(50),PF(50),PB(50),FTIME(50),
     1WETF(50),DRYF(50),Z(50),PRESDIF(50),DRIFT(50),EQIVPRES(50),HTDIFF
     2(50),RTIME(50)
      REAL INSTEMP,MA,NA
      INTEGER A,HRS,FTIME,RTIME,ABC,DEF,BARNO
      M=N=0                                                              03
C*** READ-IN HEIGHT DATA
   22 READ 93,STUTION,HRS,MINS,READING,INSTEMP,DUY,WUT,A,IPOP            03
   93 FORMAT (F8.4,2I2,F6.2,3F3.1,I2,43X,A4)
      IF (IPOP.EQ.4HENDF ) 15,15
C*** CHECK WHETHER DATA FROM BASE OR FIELD
   15 IF (STUTION.GT.0.00009)17,18                                       03
   17 N=N+1                                                              03
      IF(N.GT.50)654,655
  654 PRINT 657
  657 FORMAT(X,50(1H*),38H MORE THAN 50 FIELD READINGS IN FLIGHT)
      IERROR = -1
      GO TO 5004
  655 STATION(N) =STUTION
      IF (ABC.EQ.1HZ)6002,6001
 6001 IF(ABC.EQ.1HM)1,5001
 5001 IF(A.LE.9)200,5002
  200 PRINT 201
  201 FORMAT(X,50(1H*),29H ASKANIA SEGMENT LESS THAN 10)
      IERROR=-1
 5004 READ 5005,IPOP
 5005 FORMAT (72X,A4)
      IF(IPOP.EQ.4HENDF)5006,5004
 5006 RETURN
C*** CALCULATE FIELD PRESSURE FOR ASKANIA MICROBAROMETERS
 5002 PF(N)=SEG(I,A-9)+READING*(SEG(I,A-8)-SEG(I,A-9))/NA(I)+((A +       0
     1READING/NA(I))* MA(I)+CA(I))*(INSTEMP-20.)                         0
      GO TO 2                                                            0
 6002 PF(N)= READING
      GO TO 2
    1 PF(N) = READING * 0.7500615                                        0
    2 FTIME(N)=HRS*60+MINS                                               0
   19 GO TO 22                                                           0
   18 M=M+1                                                              0
      IF(M.GT.50)652,653
  652 PRINT 656
  656 FORMAT(X,50(1H*),38H MORE THAN 50 BASE READINGS FOR FLIGHT)
      IERROR = -1
      GO TO 5004
  653 IF(DEF.EQ.1HZ)7004,7001
 7001 IF(DEF.EQ.1HM)3,5003
C*** CALCULATE BASE PRESSURE FOR ASKANIA MICROBAROMETERS
 5003 PB(M)=SEG(J,A-9)+READING*(SEG(J,A-8)-SEG(J,A-9))/NA(J)+((A+        0
     1READING/NA(J))*MA(J)+CA(J))*(INSTEMP-20.)                          0
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      GO TO 4                                                          0:
 7004 PB(M)= READING
      GO TO 4
    3 PB(M) = READING * 0.7500515                                      0:
    4 BTIME(M)=HRS*60+MINS                                             0:
   23 DRY(M)=DUY                                                       0:
      WET(M)=WUT                                                       0:
      GO TO 22                                                         0:
   16 DO 100  JOY = 2,N
      IF (FTIME(JOY).GT.FTIME(JOY-1))100,21
   21 PRINT 92                                                         0:
   92 FORMAT(X,50(1H*),37H FIELD TIMES IN NONASCENDING SEQUENCE)
      IERROR=-1
      RETURN
  100 CONTINUE
      IF(M.EQ.0)1099,1098
C*** FOLLOWING STEP ENSURES THAT FIELD DATA CANNOT BE CALCULATED FROM PREVIOU
C*** BASE IF DATA FROM SAME IN NON-ASCENDING ORDER.
 1099 M=IZYXWV
 1098 IZYXWV=M
      DO 101 JAY =2,M
      IF (BTIME(JAY).GT.BTIME(JAY-1))101,25
   25 PRINT 91                                                         03
   91 FORMAT (50(1H*),37H BASE TIMES IN NON-ASCENDING SEQUENCE)
      IERROR=-1
      RETURN
  101 CONTINUE
      IF(M.EQ.1)1097,1096
 1097 PRINT 1095
 1095 FORMAT(X,50(1H*),32H ONLY ONE BASE STATION IN FLIGHT)
      IERROR =-1
      RETURN
 1096 K=1
      L=1
   33 IF(FTIME(K).LT.BTIME(L))26,27                                    03
C*** EXTRAPOLATE DRIFT BACKWARDS TO CORRECT FIELD READING PRECEDING FIRST BAS
C*** FOR BASE DIURNAL
   26 PRINT 90,STATION(K)
   90 FORMAT(10H STATION  ,F9.4,26H READ OUTSIDE BASE DIURNAL)
   29 WETF(K)=WET(L)-(WET(L+1)-WET(L))*(BTIME(L)-FTIME(K))/(BTIME(L+1)-BTIME(
     1TIME(L))
      DRYF(K)=DRY(L)-(DRY(L+1)-DRY(L))*(BTIME(L)-FTIME(K))/(BTIME(L+1)-B
     1TIME(L))
      Z(K)=PB(L)-(PB(L+1)-PB(L))*(BTIME(L)-FTIME(K))/(BTIME(L+1)-BTIME(L
     1))                                                               03
      IF(K.EQ.N)32,31                                                  03
   31 K=K+1                                                            03
      GO TO 33                                                         03
   27 L=L+1                                                            03
   36 IF(FTIME(K).GT.BTIME(L))35,34
C*** INTERPOLATE FOR BASE DIURNAL CORRECTIONS TO CORRECT FIELD READINGS BETWE
C*** BASE READINGS
   34 WETF(K)=WET(L)-(WET(L)-WET(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTI
     1ME(L-1))
      DRYF(K)=DRY(L)-(DRY(L)-DRY(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTI
     1ME(L-1))
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      Z(K)=PB(L)-(PB(L)-PB(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTIME(L-1))
     1))
      IF(K.EQ.N)32,37                                                   03
   37 K=K+1                                                             03
      GO TO 36                                                          03
   35 IF(L.EQ.M)38,27                                                   03
   38 PRINT 90,STATION(K)
C*** EXTRAPOLATE FORWARDS TO CORRECT FIELD READINGS READ AFTER LAST BASE READ
C*** FOR BASE DIURNAL
   40 WETF(K)=WET(L)-(WET(L)-WET(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTI
     1ME(L-1))
      DRYF(K)=DRY(L)-(DRY(L)-DRY(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTI
     1ME(L-1))
      Z(K)=PB(L)-(PB(L)-PB(L-1))*(BTIME(L)-FTIME(K))/(BTIME(L)-BTIME(L-1))
     1))
      IF(K.EQ.N)32,41                                                   03
   41 K=K+1                                                             03
      GO TO 38                                                          03
   32 DO 42K=1,N                                                        03
   42 PRESDIF(K)=PF(K)-Z(K)                                             03
      DRIFT(N)=PRESDIF(N)-PRESDIF(1)                                    03
      DO 43 L=1,N                                                       03
   43 DRIFT(L)= DRIFT(N)*(FTIME(L)-FTIME(1))/(FTIME(N)-FTIME(1) )       03
      DO 44 K=1,N                                                       03
   44 EDIVPRES(K)=PF(K)-DRIFT(K)-PRESDIF(1)                             03
      PRINT 87                                                          03
   87 FORMAT(9X,8H STATION,12X,8H HT DIFF)
C*** CALCULATE HEIGHT FROM FORMULA CLARK: PLANE AND GEODETIC SURVEYING FOURTH
C*** EDITION,VOL 2,PAGE 454 ED(4)
      DO45 L=1,N                                                        03
      LLLU1=WETF(L)*10+101
      ZZ1=60370./2.3026
      ZZ2=ALOG(Z(L)/EDIVPRES(L))
      ZZ3=1.+0.0026*COSF(2.*APPLAT)
      ZZ4=APPHT/10450000.
      ZZ5=3.*(SWVP(LLLU1)-0.00081*APPMPRES*(DRYF(L)-WETF(L)))/8./APPMPRES
     1S
      ZZ6=(ZZ3+ZZ4+ZZ5)*(1.+0.002036*9./5.*DRYF(L))
      HTDIFF(L)=ZZ1*ZZ2*ZZ6
   45 PRINT 88,STATION(L), HTDIFF(L)                                    03
   88 FORMAT ( 8X,F9.4,11X,F9.2)                                        03
      BOO = -DRIFT(N) * 38.0
      PRINT 86 ,DRIFT(N),BOO
   86 FORMAT (/,8H DRIFT =,F8.3,16H MM HG     APPROX,F7.1,6H  FEET)
      WRITE(37,1037) AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,FBARNO,ABC,
     1,BBARNO,DEF,N
 1037 FORMAT(2A4,A3,3I2,A6,A1,1X,A6,A1,I3)
      WRITE(37,1038) (STATION(L),HTDIFF(L),L=1,N)
 1038 FORMAT(6(F9.4,F8.2))
      RETURN                                                            03
      END
```

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      SUBROUTINE MNSLOPE
C*** SUBPROGRAM TO REMOVE METER DRIFT BY MEAN SLOPE TECHNIQUE AND CALCULATE
C*** OBSERVED GRAVITIES
      INTEGER WXY,AREA
      DIMENSION STATION (50),IHOURS (50),MINS(50),READING (50),TEMP(50),    04
     1ITIME(50),IA(50),IB(50),SLOPE(50),VALU(100),IATIME(50),S(50),IZ
     2(50), DRIFT(50),GRAV(50),TRUGRAV(50),LLL(20),DIFF(50),ICOUNT(7),      04
     3CONST(10,70),GRAVVAL(10,70),WXY(10),AREA(2)
      COMMON IERROR,IN,IOUT,IRES,INDGH,CONST,GRAVVAL,TRUGRAV,GRAV,DIFF,
     1TEMP,READING,DRIFT,S,VALU,STATION,SLOPE,IHOURS,MINS,ITIME,IA,IB,IA
     2TIME,IZ,LLL,WXY
      IERROR=0
      I=0
C*** READ IN AND CHECK LACOSTE GRAVITY METER DATA
  190 READ 199, METERNO,IPAP
  199 FORMAT(A6,56X,A4)
      IDECK=I
      IF(IPAP.EQ.4HENDM)102,198
  198 I=I+1
      WXY(I)=METERNO
      DO 196  L=1,7
      NN=10*L
      NNN =NN-9
      READ 197,ICOUNT(L),(GRAVVAL(I,J),J=NNN,NN)
  197 FORMAT (5X,I3,10F7.2)
  196 CONTINUE
      DO 195 J=2,7
      IF(ICOUNT(J-1)+1.EQ.ICOUNT(J))195,194
  194 PRINT 193, METERNO
  193 FORMAT(X,50(1H*),62H CARDS CONTAINING CONSTANT DATA IN INCORRECT O
     1RDER FOR METERNO,A6)
      IERROR=-1
      RETURN
  195 CONTINUE
      DO 192 L=1,7
      NN=10*L
      NNN =NN-9
      READ 167,ICOUNT(L),(CONST(I,J),J=NNN,NN)
  167 FORMAT (5X,I3,10F7.5)
  192 CONTINUE
      DO 191 J=2,7
      IF(ICOUNT(J-1)+1.EQ.ICOUNT(J))191,194
  191 CONTINUE
      GO TO 190
  102 L=0                                                                   0
C*** READ IN AREA, DATE, INSTRUMENT DATA FOR THE PARTICULAR FLIGHT
      READ 150,AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,METERNO,METTYPE,
     1U  ,IPIP
  150 FORMAT(2A4,A3,3I2,A6,A1,F8.5,40X,A4)
  500 IF(IPIP.EQ.4HENDG)103,104
  103 RETURN
  104 PRINT 151,AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,METERNO,
     1METTYPE,U
  151 FORMAT( ///,1X,2A4,3X,7HFLIGHT ,A3,3X,3I3,3X,6HMETER ,A6,A1,3X,
     1 12HSCALE FACTOR, F9.5,/)
      IF(METTYPE.NE.1HL.AND.U.LT.0.000009)400,401
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  400 PRINT 402
  402 FORMAT(X,50(1H*),19H NO METER CONSTANT)
      IERROR=-1
      GO TO 178
  401 MMM=0
C*** READ IN FIELD GRAVITY DATA
    3 READ 99,STUTION,IHOARS,MANS,RUADING,TUMP,IPOP                    0
   99 FORMAT(F8.4,2I2,F6.2,F3.1,51X,A4)
      IF(IPOP.EQ.4HENDF)653,2
    2 L=L+1                                                            0
      IF(L.GT.50)652,1
  652 PRINT 654
  654 FORMAT(X,50(1H*),40H MORE THAN 50 GRAVITY READINGS IN FLIGHT)
      GO TO 178
    1 STATION(L) = STUTION
      READING(L)=RUADING                                               0
      TEMP(L) = TUMP                                                   0
      IHOURS(L)= IHOARS                                                0
      MINS(L)  = MANS                                                  0
      ITIME(L)=IHOURS(L)*60+MINS(L)                                    0
C*** CHECK WHETHER METER LACOSTE, IF SO LOCATE METER DATA, CALCULATE GRAVITY
      IF(METTYPE.EQ.1HL)188,189
  188 DO 185 I=1,IDECK
      IF(METERNO.EQ.WXY(I))186,185
  185 CONTINUE
      PRINT 184
  184 FORMAT(X,50(1H*),35H LACOSTE GRAVITY METER DATA MISSING)
      IERROR=-1
  178 READ 179,IPOP
  179 FORMAT (72X,A4)
      IF(IPOP.EQ.4HENDF)102,178
  186 AAA=RUADING/100.
      JJ=AAA
      GRAV(L)= GRAVVAL(I,JJ+1)+(AAA-JJ)*100.*CONST(I,JJ+1)
      GO TO 3
C*** CALCULATE GRAVITY FOR METERS WITH CONSTANT SCALE FACTOR
  189 GRAV(L)=RUADING *U
      GO TO 3                                                          0
  653 IF(L.LT.2)1009,101
 1009 PRINT 1010
 1010 FORMAT(X,50(1H*),33H LESS THAN TWO STATIONS IN FLIGHT)
      IERROR = -1
      GO TO 102
  101 DO 330 I=2,L                                                     0
      IF(ITIME(I).GE.ITIME(I-1))330,415                                0
  415 PRINT 416
  416 FORMAT(X,50(1H*),37H STATION TIMES IN NON-ASCENDING ORDER)
      IERROR=-1
      GO TO 102
  330 CONTINUE                                                         0
C*** CHECK AND ADJUST ANY METER RESETS
      M=1 $ I=0                                                        0
    5 I=I+1                                                            0
      IF(I.EQ.L)9,8                                                    0
    8 J=I+1
      IF (STATION(I).EQ.STATION (J))4,5                                0
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```
    4 IF(ABSF(GRAV(J)-GRAV(I)),GE,D)6,5
    6 AA= GRAV(J)-GRAV(I)
      PRINT 98, STATION(I),IHOURS(I),MINS(I),AA                          0
   98 FORMAT (17H RESET AT STATION,F10.4,18H IMMEDIATELY AFTER,I3,I2,    0
     113H OF,F8.3,10H MILLIGALS)
      DO 7 K =J,L                                                        0
    7 GRAV(K) = GRAV(K)-AA
      GO TO 5                                                            0
    9 I=0                                                                0
C*** SET ALL IA TO ZERO FOR USE LATER IN CHECKING WHETHER DRIFT CURVE COMPLE
      DO 110 LKM=1,50                                                    0
  110 IA(LKM)=0                                                          0
C*** CALCULATE DRIFT FOR ALL DRIFT CONTROLLED PERIODS
   14 I=I+1                                                              0
      IF(I.EQ.L )10,11                                                   0
   11 J=I+1                                                              0
   16 IF(STATION(I).EQ.STATION(J))12,13                                  0
   12 IA(M)=ITIME(I)                                                     0
      IB(M)=ITIME(J)                                                     0
      SLOPE(M)=(GRAV(J)-GRAV(I))/(ITIME(J)-ITIME(I))
      M=M+1                                                              0
      GO TO 14                                                           0
   13 IF(J.EQ.L)14,15                                                    0
   15 J=J+1                                                              0
      GO TO 16                                                           0
   10 IF(M.EQ.1)1006,1007
 1006 PRINT 1008
 1008 FORMAT(X,50(1H*),27H NO DRIFT CONTROL IN FLIGHT)
      IERROR =-1
      GO TO 102
C*** CALCULATE VALUE WRT FIRST STATION - ZERO OF ALL POINTS IN FLIGHT USED F
C*** DRIFT CONTROL
 1007 VALU(1) =0.
      IATIME(1)=IA(1)                                                    0
      S(1) =SLOPE(1)                                                     0
      J=2  $ IX=2  $ IT=1                                                0
   36 IF (IA(J).EQ.0)230,231                                             0
  230 K=1  $ I=2                                                         0
      IZ(K) =IB(1)                                                       0
      IF (J.EQ.2)22,23
  231 K=J                                                                0
      IZ(K)=IA(J)                                                        0
      I=1                                                                0
   23 IF(IZ(K).GT.IB(I))20,21                                            0
   20 K=I                                                                0
      IZ(K)=IB(I)                                                        0
   21 IF(I.EQ.J-1)22,250                                                 0
  250 I=I+1  $ GO TO 23                                                  0
   22 IATIME (IX) =IZ(K)                                                 0
      VALU(IX)= VALU(IX-1)+(IATIME(IX)-IATIME(IX-1))*S(IX-1)             0
      IF(IATIME(IX).EQ.IATIME(IX-1))315,26                               0
   26 G= 60.* S(IX-1)                                                    0
C*** CHECK WHETHER ANY DRIFT COMPONENT GREATER THAN 0.15 MILLIGALS PER HOUR
      IF(ABSF(G).GT.0.15)29,315
   29 LTIME  = IATIME(IX-1)/60
      NTIME  = IATIME(IX-1) -LTIME * 60
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      LLTIME = IATIME(IX)/60
      NNTIME = IATIME(IX) -LLTIME * 60
      PRINT 89,G,LTIME,NTIME,LLTIME,NNTIME
   89 FORMAT ( 9H SLOPE OF,F9.3,23H MILLIGAL PER HOUR FROM,I3,I3,3H TO,
     1I3,I3)
  315 IF(K.EQ.J)24,25
   24 IT=IT+1
      S(IX)=(S(IX-1)*(IT-1)+SLOPE(J))/IT
      J=J+1
      GO TO 30
   25 IB(K)=IB(K)+1440
      IT=IT-1
      IF(IT.EQ.0)27,28
   28 S(IX)=(S(IX-1)*(IT+1)-SLOPE(K))/IT
   30 IF(IATIME(IX).EQ.IATIME(IX-1))317,316
C*** CHECK WHETHER ANY CHANGE IN DRIFT SLOPE GREATER THAN 0.075 MILLIGALS PE
  317 H= 60.*(S(IX)-S(IX-2))
      GO TO 319
  316 JAR= J-2
      DO 333 I=1,JAR
      IF(IATIME (IX).EQ.IB(I))35,333
  333 CONTINUE
  318 H= 60.*(S(IX)-S(IX-1))
  319 IF(ABSF(H).GT.0.075)31,35
   31 LLTIME = IATIME(IX)/60
      NNTIME = IATIME(IX) -LLTIME * 60
      PRINT 88,H ,LLTIME,NNTIME
   88 FORMAT(25H CHANGE IN DRIFT SLOPE OF,F9.3,22H MILLIGALS PER HOUR AT
     1,2I3)
      GO TO 35
   27 IF (IA(J).EQ.0)33,34
   34 IX =IX+1
      VALU(IX) = 0.
      MMM = MMM+1
      IATIME(IX) =IA(J)
      LLL(MMM) =IATIME(IX)
      LTIME = IATIME (IX-1)/60
      NTIME = IATIME (IX-1) -LTIME * 60
      LLTIME = IATIME(IX)/60
      NNTIME = IATIME(IX) - LLTIME * 60
      PRINT 87,LTIME,NTIME,LLTIME,NNTIME
   87 FORMAT (22H NO DRIFT CONTROL FROM,2I3,3H TO,2I3)
      S(IX)=SLOPE(J)
      IT=1
      J=J+1
   35 IX=IX+1
      GO TO 36
C*** CHECK WHETHER TOTAL DRIFT FOR FLIGHT GREATER THAN 0.5 MILLIGALS
   33 F= VALU(IX)-VALU(1)
      IF(ABSF(F).GT.0.5)136,37
  136 PRINT 86,F
   86 FORMAT (15H TOTAL DRIFT OF,F9.3,10H MILLIGALS)
C*** CALCULATE DRIFT AT EACH OBSERVATION TIME
   37 IF(ITIME(1).LT.IATIME(1))38,39
   38 PRINT 79
   79 FORMAT(X,50(1H*),35H FIRST STATION NOT DRIFT CONTROLLED)
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```
      IERROR=-1
      GO TO 102                                                          05
   39 I=1 $ J=1                                                          05
   46 IF(ITIME(I).LT.IATIME(J))40,41                                     05
   41 IF(ITIME(I).EQ.IATIME(J))42,43                                     05
   43 IF(J.EQ.IX)44,45                                                   05
   44 PRINT 78,STATION (I)                                               05
   78 FORMAT(X,50(1H*),6X,8H STATION,F10.4,21H NOT DRIFT CONTROLLED)
      IERROR=-1
      GO TO 102                                                          05
   45 J=J+1                                                              05
      GO TO 46                                                           05
   42 DRIFT (I)=VALU(J)                                                  05
      GO TO 49                                                           05
   40 DO 47 K =1,MMM                                                     05
      IF(IATIME(J).EQ.LLL(K))44,47                                       05
   47 CONTINUE                                                           05
      DRIFT (I)= VALU(J-1)+(ITIME(I)-IATIME(J-1))*S(J-1)                 05
   49 IF(I.EQ.L)51,50                                                    05
   50 I=I+1                                                              05
      GO TO 46                                                           05
C*** REMOVE APPROPRIATE DRIFT FROM EACH OBSERVED GRAVITY
   51 DO 48 I=1,L                                                        05
      TRUGRAV(I)=GRAV(I)-DRIFT(I)
   48 CONTINUE
      I=1  $ J=1                                                         05
   52 K=0  $ SUM = 0.                                                    05
      LN =(I-1)                                                          05
      DO 111 NL=1,LN                                                     05
      IF(STATION(I).EQ.STATION(NL)) 60,111                               05
  111 CONTINUE                                                           05
C*** CALCULATE MEAN GRAVITY VALUE FOR MULTIPLY READ STATIONS
   57 IF (STATION(I).EQ.STATION(J))53,54                                 05
   53 SUM= SUM + TRUGRAV(J)                                              05
      K= K+1                                                             05
   54 IF(J.EQ.L)55,56                                                    05
   56 J=J+1                                                              05
      GO TO 57                                                           05
   55 AVGRAV =SUM/K                                                      05
      J=I                                                                05
   62 IF(STATION (I).EQ.STATION(J))58,59                                 05
   58 DIFF(J) =TRUGRAV(J)-AVGRAV                                         05
      TRUGRAV(J)=AVGRAV                                                  05
   59 IF(J.EQ.L)50,61                                                    05
   61 J=J+1                                                              05
      GO TO 62                                                           05
   60 IF(I.EQ.L)63,64                                                    05
   64 J=I $ I=I+1                                                        05
      GO TO 52                                                           05
   63 PRINT 71                                                           05
   71 FORMAT (3X,8H STATION,4X,8H GRAVITY,7X,5H TIME,6X,6H DRIFT,7X,
     15H DIFF)
C*** FOR EACH STATION CALCULATE CALCULATE GRAVITY DIFFERENCE FROM FIRST
      ANSWER = TRUGRAV(1)
      DO 201 I=1,L
  201 TRUGRAV(I) =TRUGRAV(I)-ANSWER
```

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```
      DO 65 I=1,L                                                        05
   65 PRINT 70,STATION(I),TRUGRAV(I),IHOURS(I),MINS(I),DRIFT(I),DIFF(I)
   70 FORMAT(X,F10.4,4X,F8.2,6X,2I3,4X,F8.2,4X,F8.2)
      WRITE(37,1037) AREA(1),AREA(2),IFLIGHT,IDAY,MONTH,IYEAR,METERNO,MET
     1TTYPE,J,L
 1037 FORMAT(2A4,A3,3I2,A6,A1,F8.5,I3)
      WRITE(37,1038) (STATION(I),TRUGRAV(I),I=1,L)
 1038 FORMAT(6(F9.4,F8.2))
      GO TO 102                                                          05
      END                                                                05
```

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      SUBROUTINE FILEMAN
C IF IERROR = 1 UPDATE AND IF 2 CREATE
C     UPDATE SAF FILE WITH GRAVITY OR HEIGHT RESULTS
      COMMON IERROR,IN,IOUT,IRES,INDGH,DUMMY(2000),RESULT(2000),ISTNS(2,
     12000)
      DIMENSION IAREACD(20),LABEL(20),MABEL(20)
C CHECK TAPE LABEL
      READ(60,1050)LABEL
 1050 FORMAT(20A4)
   54 READ(IN,1050)MABEL
      DO 51 N=1,20
      IF(LABEL(N)-MABEL(N))52,51,52
   51 CONTINUE
      WRITE(IOUT,1050)LABEL
      GO TO 53
   52 WRITE(61,1051)MABEL,IN,LABEL
 1051 FORMAT(X,6H TAPE ,20A4,13H LOADED ON LU,I3,/,11H SHOULD BE ,20A4)
      STOP
   53 READ(60,1050)IAREACD
      GO TO (7,43)IERROR
    7 IFOUND=IEND=0
      WRITE(61,2001)LABEL,IAREACD
 2001 FORMAT(1H1,X,32HRESULTS USED TO UPDATE TAPE NAME/,X,20A4,//,27H FI
     1LE ON TAPE UPDATED NAMED,/,X,20A4)
   63 READ(IN,1050)LABEL
      WRITE(IOUT,1050)LABEL
      IF(LABEL(1),EQ,4HENDS)94,55
C     CHECK TO SEE IF AREA FOUND AND GIVE DIAGNOSTIC IF NOT
94    IF(IFOUND-1)56,57,56
   56 WRITE(61,1056)IAREACD,MABEL
1056  FORMAT(X,50(1H*),5HAREA ,20A4,16HNOT ON SAF FILE ,20A4)
C   SWITCH INPUT AND OUTPUT UNITS
   57 WRITE(61,1057)IOUT
 1057 FORMAT(X,13HLOGICAL UNIT ,I3,3X,21HIS LATEST OUTPUT TAPE)
      REWIND IN
      REWIND IOUT
86    RETURN
C   CHECK AREA
   55 DO 58 K=1,20
      IF(LABEL(K)-IAREACD(K))59,58,59
   58 CONTINUE
      IFOUND=1
      GO TO 60
C  COPY 1 AREA TO UPDATED TAPE
   59 READ(IN,1059)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
 1059 FORMAT(A4,X,A4,2F10.2,2F8,2)
      IF (EOF,IN)61,62
   62 WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
 1062 FORMAT(A4,1H,,A4,2F10.2,2F8,2)
      GO TO 59
   61 ENDFILE IOUT
      GO TO 63
C*****UPDATE AREA THAT HAS BEEN FOUND
   60 IEND=IR=0
      KTR=0
  201 KTR=KTR+1
```

```
      IF(KTR.GT.IRES)211,212
  212 IF(RESULT(KTR).LE.-9.E10)201,202
  202 IF(IEND .EQ.1)205,230
  230 READ(IN,1059)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
      IF (EOF,IN)233,204
  233 IEND=1
      GO TO 205
  204 IF(ISTN1-ISTNS(1,KTR))207,206,205
  206 IF(ISTN2-ISTNS(2,KTR))207,208,205
C*****UPDATE RECORD
  208 IF(INDSH.EQ.3RHTS)209,210
  209 WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,RESULT(KTR),GRAV
      GO TO 201
  210 WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,ELEV,RESULT(KTR)
      GO TO 201
C*****NO RECORD ON TAPE FOR RECORD IN CORE
  205 WRITE(61,1205)ISTNS(1,KTR),ISTNS(2,KTR)
 1205 FORMAT(X,50(1H*),29HNO RECORD ON FILE FOR STATION  ,4X,A4,1H,,A4)
      IF(INDSH.EQ.3RHTS)215,214
  214 WRITE(IOUT,1214)ISTNS(1,KTR),ISTNS(2,KTR),RESULT(KTR)
 1214 FORMAT(A4,1H,,A4,2(10H -99999.00),8H -999.00,F8.2)
      GO TO 216
  215 WRITE(IOUT,1215)ISTNS(1,KTR),ISTNS(2,KTR),RESULT(KTR)
 1215 FORMAT(A4,1H,,A4,2(10H -99999.00),F8.2,8H -999.00)
  216 KTR=KTR+1
      IF(KTR.GT.IRES)234,235
  234 IR=1
      IF(IEND.EQ.1)203,220
  235 IF(RESULT(KTR).LE.-9.E10)216,304
  304 IF(IEND.EQ.1)205,204
C*****NO RECORD IN CORE FOR RECORD ON TAPE
  207 WRITE(61,1207)ISTN1,ISTN2
 1207 FORMAT(X,50(1H*),37HNO DATA TO UPDATE RECORD FOR STATION ,A4,1H,,
     1A4)
      WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
      GO TO 202
C*****END OF DATA IN CORE COPY AREA TO END
  211 READ(IN,1059)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
      IF (EOF,IN)203,220
  220 WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
      IF(IR.EQ.1)310,211
  310 WRITE(61,1207)ISTN1,ISTN2
      GO TO 211
  203 ENDFILE IOUT
      GO TO 63
C     CREATE A FILE OF RECORDS OF STN LAT LONG HEIGHT GRAVITY
C     FORMAT A4,1H,,A4,2F10.2 ,2F8.2   WITH -99... WHERE NO DATA
C     AVAILABLE , INPUT TAPE -SAF FILE ON LU IN, OUTPUT ON LU IOUT
C     READ AREA LABEL
   43 WRITE(61,2002)LABEL,IAREACD
 2002 FORMAT(1H1,X,42HRESULTS USED TO CREATE A FILE ON TAPE NAME/,X,20A4
     1,//,X,22H FILE CREATED IS NAMED,/,X,20A4,//,X,56H THE FOLLOWING FI
     2LES WERE ON TAPE PRIOR TO LATEST CREATE)
      GO TO 2051
 2052 WRITE(61,2053)LABEL
 2053 FORMAT(X,20A4)
```

```
2051 READ(IN,1050)LABEL
     IF(IOCHECK,IN)2051,70
  70 IF(LABEL(1).EQ.4HENDS)38,41
  41 WRITE(IOUT,1050)LABEL
  42 READ(IN,1036)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
1036 FORMAT(A4,X,A4,2F10.2,2F8.2)
   5 IF(EOF,IN)401,402
 402 WRITE(IOUT,1062)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAV
     GO TO 42
 401 ENDFILE IOUT
     GO TO 2052
  38 WRITE(IOUT,1050)IAREACD
     DO 45 J=1,IRES
     IF(RESULT(J) .LE. -9.E10)45,46
  46 IF(INDGH.EQ.3RHTS)47,48
  47 WRITE(IOUT,1047)ISTNS(1,J),ISTNS(2,J),RESULT(J)
1047 FORMAT(A4,1H.,A4,2(10H -99999.00),F8.2,8H -999.00)
     GO TO 45
  48 WRITE(IOUT,1048)ISTNS(1,J),ISTNS(2,J),RESULT(J)
1048 FORMAT(A4,1H.,A4,2(10H -99999.00),8H -999.00,F8.2)
  45 CONTINUE
     ENDFILE IOUT
     WRITE(IOUT,1058)
1058 FORMAT(6HENDSAF,74X)
     REWIND  IN
     REWIND IOUT
     WRITE(61,1049)IOUT
1049 FORMAT(X,13HLOGICAL UNIT ,I3,3X,21HIS LATEST OUTPUT TAPE )
     END
```

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```
      SUBROUTINE LEASTSQ
C*****ADJUST FOR 3500 AND FOR 3200 PROGRAMS OVERLAYED.
C  INPUT NODE LISTS AND ORGANIZE INTO SORTED LIST
C  IMPROVED CHECKING FACILITY SHOULD BE INCORPORATED LATER EG CHECK FOR ENDN
      DIMENSION AMAT(7260),RHS(120,1)
      DIMENSION L3(200),L4(800)
      DIMENSION NODES(2,150),ITEMPA(2,400),TEMPC(400),ITEMPB(2,400)
      DIMENSION ITEM(2),WEIGHTS(100),DIFF(200),NSTN(200),MSTN(200)
      DIMENSION ICARD(20),ISTNS1(2),ISTNS2(2)
      DIMENSION RESULT(2000),ISTNS(2,2000)
      COMMON IERROR,IN,IOUT,IRES,INDGH,AMAT,L4
      EQUIVALENCE (ITEXT,NODES)
      DIMENSION ITEXT(20)
      DIMENSION TEMPR(50)
      EQUIVALENCE (ITEMPA,AMAT),(TEMPC,AMAT(801)),(ITEMPB,AMAT(1201))
      EQUIVALENCE (RESULT,AMAT(2001)),(ISTNS,AMAT(4001))
C*****THIS LEAVES ITEMPA AND TEMPC AVAILABLE AS SCRATCH PADS
C**** ARRRAYS NOT CONSISTENT WITHIN THEMSELVES,DIMENSIONS SO TO ENSURE NO OV
      IERROR=0
C**PHASE 1. INPUT NODE DATA SORT AND OUTPUT
      WRITE(61,1051)
 1051 FORMAT(1H1,20X,30HLEAST SQUARES ADJUSTMENT PHASE)
      READ(60,1000)NAREAS,NNODES,NFIXED,DATUM,DEVMAX,ADJMAX
      WRITE(61,4000)NAREAS,NNODES,NFIXED,DATUM,DEVMAX,ADJMAX
 4000 FORMAT(//,X,34HNUMBER OF AREAS TO ADJUST TOGETHER,4X,I2,//,X,21HTO
     1TAL NUMBER OF NODES,4X,I3,//,X,21HNUMBER OF FIXED NODES,4X,I3,//,X
     2,18HWORK TO A DATUM OF,4X,F8.1,//,X,70HTERMINATE PROCESSING IF STA
     3NDARD DEVIATION OF ADJUSTMENTS GREATER THAN,4X,F5.2,/,X,37HOR IF M
     4AXIMUM ADJUSTMENT GREATER THAN,4X,F5.2)
 1000 FORMAT(I2,2I3,F8.1,2F5.2)
      READ(60,1001)((ITEMPA(J,K),J=1,2),K=1,NNODES)
 1001 FORMAT(2A4)
      READ(60,1002)((ITEMPB(J,K),J=1,2),TEMPC(K),K=1,NFIXED)
 1002 FORMAT(2A4,F8.2)
C  READ ENDNODES CARD TO CHECK IF CORRECT NUMBER OF NODES
C  THIS CHECK SHOULD BE ADEQUATE BUT MAY RESULT IN NEXT BLOCK OF DATA
C  BEING IGNORED.
      READ(60,1003)IT1,IT2
 1003 FORMAT(2A4)
      IF(IT1.NE.4HENDN.OR.IT2.NE.4HODES)1,2
    1 WRITE(61,1004)
 1004 FORMAT(X,50(1H*),15HNODE DATA ERROR)
      IERROR=-1
      RETURN
C  COPY NON FIXED NODES INTO ARRAY NODES
    2 K=1
      DO 3 I=1,NNODES
      ITEM(1)=ITEMPA(1,I)
      ITEM(2)=ITEMPA(2,I)
      CALL SSEARCH(ITEM,ITEMPB,NFIXED,IPOSN)
      IF(IPOSN.EQ.-1)4,3
    4 NODES(1,K)=ITEM(1)
      NODES(2,K)=ITEM(2)
      K=K+1
    3 CONTINUE
C  CHECK IF ALL FIXED NODES ARE IN NODE LIST
```

```
      MM=NNODES-K+1
      MMM=NFIXED-MM
      IF(MM.NE.NFIXED)8,9
    8 WRITE(61,1007)MMM
 1007 FORMAT(X,50(1H*),I6,28HFIXED NODES NOT IN NODE LIST)
      IERROR=-1
      RETURN
C  SORT NON FIXED NODES
    9 NFREE=NNODES-NFIXED
      CALL SORT2(NODES,NFREE)
C  SORT FIXED NODES IN INPUT AREA
      CALL SORT22(ITEMPB,TEMPC,NFIXED)
C  TRANSFER FIXED NODES TO NODE LIST
      DO 5 I=1,NFIXED
      INF=I+NFREE
      NODES(1,INF)=ITEMPB(1,I)
C*************1
    5 NODES(2,INF)=ITEMPB(2,I)
C  SET HEIGHTS VECTOR ZERO FOR FREE AND HEIGHTS FOR FIXED STATIONS
      DO 6 I=1,NFREE
    6 HEIGHTS(I)=0
      DO 7 I=1,NFIXED
      INF=I+NFREE
    7 HEIGHTS(INF)=TEMPC(I)-DATUM
C  PRINT SORTED NODE LIST WITH HEIGHTS FOR FIXED STATIONS
      WRITE(61,1005)((NODES(J,K),J=1,2),K=1,NFREE)
 1005 FORMAT(1H ,6X,9HNODE LIST,//,19H    NODE        VALUE,//,(X,A4,1H,,
     1A4))
      N=NFREE+1
      WRITE(61,1006)((ITEMPB(J,K),J=1,2),TEMPC(K),K=1,NFIXED)
 1006 FORMAT(X,A4,1H,,A4,F10.2)
C CHECK THAT NO STATION NODE IS LISTED TWICE
      KKK=NNODES-1
      DO 507 I=1,KKK
      IF(NODES(1,I).EQ.NODES(1,I+1).AND.NODES(2,I).EQ.NODES(2,I+1))506,5
     107
  507 CONTINUE
      IF(IERROR.EQ.-1)5508,508
 5508 RETURN
  506 WRITE(61,1507)NODES(1,I),NODES(2,I)
 1507 FORMAT(X,50(1H*),A4,1H,,A4,2X,21HLISTED MORE THAN ONCE )
      IERROR = -1
      GO TO 507
C*****PHASE 2 READ FLIGHT DATA AND SET UP CONNECTION LIST 2 ARRAYS
C*****NSTN AND MSTN FOR STATION NUMBERS(I.E. POSITIONS IN NODES ARRAY 1 TO
C*****NNODES) AND ARRAY DIFF, FOR OBSERVED HEIGHT DIFFERENCES. NSTN AND MSTN
C*****FORM LISTL1, DIFF FORMS LIST L2 USING NOTATION OF PROGRAM DOCUMENTATION
  508 KTAREAS=0
      KTL1=1
C*****THIS NEXT STATEMENT PUT IN TO OVERCOME POSSIBLE SOFTWARE BUG
      REWIND 37
   20 CONTINUE
 2020 READ(37,1008)ICARD
 1008 FORMAT(20R4)
   14 READ (37,1009)IAREA1,IAREA2,IFLIGHT,IDAY,MONTH,IYEAR,METNO,METYPE,
     1U,NOSTNS
```

```
 1009 FORMAT(2A4,A3,3I2,A6,A1,A8,I3)
      IF(EOF,37) 10,11
   10 KTAREAS=KTAREAS+1
      IF(KTAREAS.EQ.NAREAS)12,20
   11 READ(37,1050) ((ITEMPA(I,J),I=1,2),TEMPC(J),J=1,NOSTNS)
 1050 FORMAT(6(A4,X,A4,F8.2))
      ISCAN=1
 2000 IF(ISCAN-1.EQ.NOSTNS)14,15
   15 ISTNS1(1)=ITEMPA(1,ISCAN)
      ISTNS1(2)=ITEMPA(2,ISCAN)
      ISCAN=ISCAN+1
      CALL SSEARCH(ISTNS1,NODES,NNODES,IPOSN)
      IF(IPOSN.EQ.-1)2000,13
   13 N=IPOSN
  101 HN=TEMPC(ISCAN-1)
   17 IF(ISCAN-1.EQ.NOSTNS)14,16
   16 ISTNS2(1)=ITEMPA(1,ISCAN)
      ISTNS2(2)=ITEMPA(2,ISCAN)
      ISCAN=ISCAN+1
C**************2
      CALL SSEARCH(ISTNS2,NODES,NNODES,IPOSN)
      IF(IPOSN.EQ.-1)17,18
   18 M=IPOSN
      HM=TEMPC(ISCAN-1)
      IF(N.EQ.M)101,19
   19 NSTN(KTL1)=N
      MSTN(KTL1)=M
      DIFF(KTL1)=HN-HM
      KTL1=KTL1+1
      N=M
      HN=HM
      GO TO 17
   12 IF (KTL1.GT.1500)21,22
   21 WRITE(61,1010)
 1010 FORMAT(X,50(1H*),32HMORE THAN 1500  LINES IN NETWORK)
      IERROR=-1
      RETURN
C*****OUTPUT CONNECTION TABLE AS STN STN DIFF WITH FIXED STATIONS
C*****MARKED FIXED AND TOTAL NUMBER OF LINES IN THE NETWORK
   22 KTL1=KTL1-1
      REWIND 37
      WRITE(61,1014)
 1014 FORMAT(1H1,X,16HCONNECTION TABLE,/7,3X,4HNODE,13X,4HNODE,12X, 10HD
     1IFFERENCE,/)
C**************3
      DO 23 J=1,KTL1
      IFIX11=4R
      IFIX12=2R
      IFIX21=4R
      IFIX22=2R
      N=NSTN(J)
      IF(N.GT.NFREE)24,25
   24 IFIX11=4R FIX
      IFIX12=2RED
   25 M=MSTN(J)
      IF(M.GT.NFREE)26,27
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   26 IFIX21=4R FIX
      IFIX22=2RED
   27 WRITE(61,1011)   NODES(1,N),NODES(2,N),IFIX11,IFIX12,NODES(1,M),NO
     1DES(2,M),IFIX21,IFIX22,DIFF(J)
 1011 FORMAT(X,A4,1H,,A4,R4,R2,2X,A4,1H,,A4,R4,R2,2X,F8,2)
   23 CONTINUE
      WRITE(61,1012)KTL1
 1012 FORMAT(/,X,33HNUMBER OF LINES IN THE NETWORK = ,I4)
C*****CONSTRUCT LIST L3 THE PROGRESSIVE SUM OF LINES INTO NODES 1 TO
C*****NNODES,AND LISTL4 THE LIST OF LINES CONNECTED TO THE FREE NODES
      L3(1)=0
      KTL4=1
      DO 28 NN=1,NFREE
      DO 31 NQ=1,KTL1
      IF(NSTN(NQ).EQ.NN.OR.MSTN(NQ).EQ.NN)30,31
   30 L4(KTL4)=NQ
      KTL4=KTL4+1
      IF(KTL4.GT.3200)32,31
   32 WRITE(61.1013)KTL4
 1013 FORMAT(X,48HNETWORK OVERFLOWS ARRAY L4 DIM 3200 NETWORK NEED,I4)
      IERROR=-1
      RETURN
   31 CONTINUE
      L3(NN+1)=KTL4-1
      IF(L3(NN).EQ.L3(NN+1))64,28
C*****WRITE DIAGNOSTIC AND CARRY ON
C*************4
   64 WRITE(61,1017)NODES(1,NN),NODES(2,NN)
 1017 FORMAT(X,6HNODE  ,A4,1H,,A4,47HNOT CONNECTED TO ANY OTHER SEE CONN
     1ECTION TABLE)
      IERROR=-1
   28 CONTINUE
      IF(IERROR.EQ.-1)47,33
   47 RETURN
C*****CONSTRUCT MATRIX OF NORMAL EQUATIONS STORED AS A LINEAR ARRAY AMAT
C*****AND USE SYMINV TO OBTAIN THE SOLUTIONS. PROGRAM FOR 3600 WILL NEED
C*****TO HAVE SOURCE DECK OF SYMINV AND USE VARIABLE DIMENSION FACILITY.
C
C     NOTE MATRIX IS SYMMETRIC AND IS DETERMINED ROW BY ROW BUT STORED
C     COLUMN BY COLUMN.
   33 DO 34 NN=1,NFREE
      K=NFREE*(NN-1)-(NN-2)*(NN-1)/2
      DO 35 I=NN,NFREE
      L=K+I-NN+1
   35 AMAT(L)=0
      NLINES=L3(NN+1)-L3(NN)
      SIGX1=0
      ISTL4=L3(NN)
C  INSERT COEFF OF NODE NN EQUAL TO NUMBER OF LINES JOINING NODE
      L=K+1
      AMAT(L)=NLINES
C  ADD -1 TO COEFFICIENTS OF REMAINING NODES JOINED TO NODE NN FOR EACH
C  LINE CONNECTING THAT NODE NN, NOTE MULTIPLE OBSERVATIONS OF A
C  LINE ARE PERMISSIBLE. ALSO CONSTRUCT RHS TERM.
      DO 36 J=1,NLINES
      LL4=ISTL4+J
```

```
      LINE=L4(LL4)
C**************5
      IF(MSTN(LINE).EQ.NN)37,38
   37 JJ=MSTN(LINE)
      SIGXI=SIGXI+DIFF(LINE)
      GO TO 39
   38 JJ=MSTN(LINE)
      SIGXI=SIGXI-DIFF(LINE)
   39 IF(JJ.GT.NFREE)40,41
   40 SIGXI=SIGXI+HEIGHTS(JJ)
      GO TO 36
   41 IF(JJ.LT.NN)36,42
   42 L=K+JJ-NN+1
      AMAT(L)=AMAT(L)-1
   36 CONTINUE
      RHS(NN,1)=SIGXI
   34 CONTINUE
C*****SOLVE NORMAL EQUATIONS USING SYMINV
      CALL SYMINV(AMAT,NFREE,RHS,1,DET,IRR)
 3000 IF(IRR.EQ.1)43,46
   43 WRITE(61,1015)
 1015 FORMAT(X,55HSINGULAR MATRIX OF NORMAL EQUATIONS DETECTED BY SYMINV
     1 )
      IERROR=-1
      RETURN
C*****TRANSFER LEAST SQUARES VALUES TO HEIGHT/GRAVITY LIST ARRAY HEIGHTS
   46 DO 44 K=1,NFREE
   44 HEIGHTS(K)=RHS(K,1)+DATUM
      N=NFREE+1
      DO 110 K=N,NNODES
  110 HEIGHTS(K)=HEIGHTS(K)+DATUM
C*****OUTPUT COMPUTED HEIGHTS
      WRITE(61,1016)((NODES(J,K),J=1,2),HEIGHTS(K),K=1,NFREE)
 1016 FORMAT(1H1,X,36HLEAST SQUARES VALUES FOR FREE POINTS,//,16H   NODE
     1       VALUE,/,(X,A4,1H.,A4,F8,2))
C*****COMPUTE ADJUSTMENTS TO LINES,THE STD DEVIATION AND THE MAXIMUM
C*****ADJUSTMENT,LIST THE CONNECTION LIST WITH YHIS DATA.TERMINATE
C*****PROCESSING IF STD DEV GT SPECIFIED OR MAX ADJUSTMENT GT SPECIFIED
      ADJMAXO=0.
C**************6
      STDDEV=0.
      SIGX=0.
      SIGX2=0.
      WRITE(61,1018)
 1018 FORMAT(1H1,X,32HCONNECTION TABLE AND ADJUSTMENTS,//,3X,4HNODE,13X,
     14HNODE,12X,10HDIFFERENCE,2X,10HADJUSTMENT,//)
      DO 50 J=1,KTL1
      IFIX11=4R
      IFIX12=2R
      IFIX21=4R
      IFIX22=2R
      N=MSTN(J)
      IF(N.GT.NFREE)51,52
   51 IFIX11=4R FIX
      IFIX12=2RED
   52 M=MSTN(J)
```

```
      IF(M.GT.NFREE)53,54
   53 IFIX21=4R FIX
      IFIX22=2RED
   54 ADJ=HEIGHTS(N)-HEIGHTS(M)-DIFF(J)
      SIGX=SIGX+ADJ
      SIGX2=SIGX2+ADJ*ADJ
      IF(ABSF(ADJ).GT.ADJMAXC)55,56
   55 ADJMAXC=ABSF(ADJ)
   56 WRITE(61,1019) NODES(1,N),NODES(2,N),IFIX11,IFIX12,NODES(1,M),
     1NODES(2,M),IFIX21,IFIX22,DIFF(J),ADJ
 1019 FORMAT(X,A4,1H.,A4,R4,R2,2X,A4,1H.,A4,R4,R2,2X,F8.2,F12.2)
   50 CONTINUE
      AMEAN=SIGX/KTL1
      STDDEV=SQRT(SIGX2/KTL1-AMEAN*AMEAN)
      WRITE(61,1020) STDDEV,AMEAN,ADJMAXC
C*************7
 1020 FORMAT(//,X,36HSTANDARD DEVIATION OF ADJUSTMENTS = ,F8.2,/,X,
     122HMEAN OF ADJUSTMENTS = ,F8.2,/,X,21HMAXIMUM ADJUSTMENT = ,F8.2)
      IF(ADJMAXC.GT.ADJMAX.OR.STDDEV.GT.DEVMAX)60,57
   60 IERROR=-1
      RETURN
C*****READ RED FILE AND ADJUST EACH FLIGHT ONTO THE STATIONS COMPUTED
C*****BY LEAST SQUARES.FOR GRAVITY DATA MISCLOSES ARE DISTRIBUTED EVENLY
C*****BETWEEN THE STATIONS.FOR HEIGHTS THE MISCLOSE IS DISTRIBUTED IN
C*****PROPORTION TO THE DIFFERENCES.STATION CODES AND FINAL RESULTS ARE
C*****TO BE HELD IN ARRAYS RESULT AND ISTNS READY FOR SORTING.USE
C*****ITEMPA(2,200) AND ITEMPC AS SCRATCH PADS
   57 KTAREAS=0
      IRES=1
C*****THIS NEXT STATEMENT PUT IN TO OVERCOME POSSIBLE SOFTWARE BUG
   69 IF (EOF,37)2069,2069
 2069 READ(37,1008)ICARD
      WRITE(61,1025) ICARD
 1025 FORMAT(1H1,20HADJUSTED FLIGHT DATA,/,X,20R4)
   67 M=N=0
      MARK1=1
   70 READ (37,1009)IAREA1,IAREA2,IFLIGHT,IDAY,MONTH,IYEAR,METNO,METYPE,
     1U,NOSTNS
      IF(EOF,37) 66,113
  113 READ(37,1050) ((ITEMPA(I,J),I=1,2),TEMPC(J),J=1,NOSTNS)
      ISCAN=1
      WRITE(61,2009)IAREA1,IAREA2,IFLIGHT,IDAY,MONTH,IYEAR,METNO,METYPE,
     1U
 2009 FORMAT(//,10X,2A4,10H FLIGHT NO,A3,6X,3I3,6X,A6,A1,6X,A8)
      WRITE(61,2010)
 2010 FORMAT(10X,8H STATION,13X,5HVALUE)
  102 IF(ISCAN-1.EQ.NOSTNS)72,71
   66 KTAREAS=KTAREAS+1
      IF(KTAREAS.EQ.NAREAS)68,69
   72 IF(N.EQ.0)73,94
   73 WRITE(61,1021)
 1021 FORMAT(X,50(1H*),62HPOSSIBLE ERROR.THIS FLIGHT HAS NO NODE STATION
     1.FLIGHT IGNORED.)
      GO TO 70
   71 ISTNS1(1)=ITEMPA(1,ISCAN)
      ISTNS1(2)=ITEMPA(2,ISCAN)
```

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```
      ISCAN=ISCAN+1
C**************8
      CALL SSEARCH(ISTNS1,NODES,NNODES,IPOSN)
      IF(IPOSN.EQ.-1)102,74
   74 MARK2=ISCAN-1
      M=N
      N=IPOSN
      IF(M.EQ.0)75,76
   76 INTVS=MARK2-MARK1
C**** AND SET M=0 WHEN COMPLETED THEN GO TO 67 FOR REST OF FLIGHT
C**** IN WHICH CASE ENTER ONLY THE VALUE ONCE IN THE LIST FOR SORTING
C**** ADJUST BETWEEN TWO FIXED STATIONS UNLESS ADJACENT IN FLIGHT LIST
      IF(INTVS.EQ.1)108,80
   80 DMISCL=HEIGHTS(N)-HEIGHTS(M)-(TEMPC(MARK2)-TEMPC(MARK1))
C**** TEST FOR GRAVITY OR HEIGHTS
      IF(INDGH.EQ.3RHTS)81,82
C**** ADJUST FOR HEIGHTS
   81 SUMDIF=0.
      DO 83 KK=1,INTVS
      JJ=MARK1+KK
   83 SUMDIF=SUMDIF+ABS(TEMPC(JJ)-TEMPC(JJ-1))
      IADJ=INTVS-1
C**** PUT STATION AND ADJUSTED RESULT IN LISTS FOR SORTING,OMIT NODE STATION
C**** THIS STAGE
      SUMADJ=0.
      DO 84 KK=1,IADJ
      JJ=MARK1+KK
      ISTNS(1,IRES)=ITEMPA(1,JJ)
      ISTNS(2,IRES)=ITEMPA(2,JJ)
      ADJV=ABS(TEMPC(JJ)-TEMPC(JJ-1))*DMISCL/SUMDIF
      SUMADJ=SUMADJ+ADJV
      RESULT(IRES)=HEIGHTS(M)+SUMADJ+TEMPC(JJ)-TEMPC(MARK1)
      TEMPB(JJ)=RESULT(IRES)
   84 IRES=IRES+1
C**************9
  108 TEMPB(MARK1)=HEIGHTS(M)
      TEMPB(MARK2)=HEIGHTS(N)
C**** OUTPUT FLIGHT BETWEEN TWO NODE STATIONS
      MARK11=MARK1+1
      WRITE(61,2006) ((ITEMPA(I,J),I=1,2),TEMPB(J),J=MARK11,MARK2)
 2006 FORMAT(8X,A4,1H.,A4,10X,F10,2)
   78 M=N
   77 MARK1=MARK2
      GO TO 102
C**** ADJUST FOR GRAVITY
   82 IADJ=INTVS-1
      SUMADJ=0.
      ADJV=DMISCL/INTVS
      DO 85 KK=1,IADJ
      JJ=MARK1+KK
      ISTNS(1,IRES)=ITEMPA(1,JJ)
      ISTNS(2,IRES)=ITEMPA(2,JJ)
      SUMADJ=SUMADJ+ADJV
      RESULT(IRES)=HEIGHTS(M)+SUMADJ+TEMPC(JJ)-TEMPC(MARK1)
      TEMPB(JJ)=RESULT(IRES)
   85 IRES=IRES+1
```

```
      GO TO 108
C**** ADJUST FORWARD AS LAST STATION NOT FIXED,ADJUST FROM MARK1
C**** TO ISCAN-1 IN FLIGHT STATION SEQUENCE,ADJUST BY ADDING CALCULATED
C**** MINUS OBSERVED VALUE OF NODE STATION TO THE REMAINING STATIONS IN
C**** THE FLIGHT
   94 INTVS=ISCAN-1-MARK1
      IF(INTVS.EQ.0)67,107
  107 MARK2=ISCAN-1
      ADJ=HEIGHTS(N)-TEMPC(MARK1)
      DO 86 KK=1,INTVS
      JJ=MARK1+KK
      ISTNS(1,IRES)=ITEMPA(1,JJ)
      ISTNS(2,IRES)=ITEMPA(2,JJ)
      RESULT(IRES)=TEMPC(JJ)+ADJ
      TEMPB(JJ)=RESULT(IRES)
   86 IRES=IRES+1
      TEMPB(MARK1)=HEIGHTS(N)
      MARK11=MARK1+1
      WRITE(61,2006) ((ITEMPA(I,J),I=1,2),TEMPB(J),J=MARK11,MARK2)
C**** CARRY ON TO THE NEXT FLIGHT
C**************10
      GO TO 67
C**** ADJUST BACKWARD AS FIRST STATION NOT FIXED,ADJUST FROM MARK1 TO
C**** MARK2 BY ADDING CALCULATED MINUS OBSERVED VALUE OF NODE STATION
C**** AT MARK2
   75 INTVS=MARK2-1
      IF(INTVS.EQ.0)105,106
  106 ADJ=HEIGHTS(N)-TEMPC(MARK2)
      DO 87 KK=1,INTVS
      ISTNS(1,IRES)=ITEMPA(1,KK)
      ISTNS(2,IRES)=ITEMPA(2,KK)
      RESULT(IRES)=TEMPC(KK)+ADJ
      TEMPB(KK)=RESULT(IRES)
   87 IRES=IRES+1
  105 TEMPB(MARK2)=HEIGHTS(N)
      WRITE(61,2006) ((ITEMPA(I,J),I=1,2),TEMPB(J),J=1,MARK2)
      M=N
      MARK1=MARK2
      GO TO 102
C**** PUT NODES AND VALUES INTO RESULT LIST FOR SORTING
   68 DO 88 KK=1,NNODES
      ISTNS(1,IRES)=NODES(1,KK)
      ISTNS(2,IRES)=NODES(2,KK)
      RESULT(IRES)=HEIGHTS(KK)
   88 IRES=IRES+1
      IRES=IRES-1
C**** SORT THE FINAL RESULTS INTO ASCENDING ORDER FOR UPDATING
C**** THE SAF FILE.LIST THE SORTED RESULTS FOR REFERENCE.IF THERE ARE
C**** DIFFERENT VALUES FOR A STATION LIST THEM INDEPENDENTLY
      CALL SORT22(ISTNS,RESULT,IRES)
      ITEXT(1)=4R
      ITEXT(2)=4R
      ITEXT(3)=4R MUL
      ITEXT(4)=4RTIPL
C**************11
      ITEXT(5)=4RE VA
```

```
      ITEXT(6)=4RLUES
      ITEXT(7)=4R AT
      ITEXT(8)=4RTHIS
      ITEXT(9)=4R STA
      ITEXT(10)=4RTION
      ITEXT(11)=ITEXT(12)=ITEXT(13)=ITEXT(14)=ITEXT(15)=ITEXT(16)=ITEXT(1
     117)=ITEXT(18)=ITEXT(19)=ITEXT(20)=4R
      IRESD=IRES
      IND=0
      J=11
      K=20
      IPAGE=1
      KTR=0
  111 WRITE(61,1024) ICARD,IPAGE
 1024 FORMAT(1H1,50X,19HFINAL SORTED VALUES,//,28X,20R4,14X,5H PAGE,I6)
      DO 97 LINE =1,50
      KTR=KTR+1
      IF(KTR.LT.IRES)92,93
   92 IF(ISTNS(1,KTR).NE.ISTNS(1,KTR+1).OR.ISTNS(2,KTR).NE.ISTNS(2,KTR+1
     1))114,91
   91 IND=1
      J=1
      K=10
      GO TO 90
   93 IF(KTR.EQ.IRES)114,122
  114 J =11
      IND = 0
      K=20
   90 WRITE(61,121)(ISTNS(I,KTR),I=1,2),RESULT(KTR),(ITEXT(L),L=J,K)
  121 FORMAT (20X,A4,1H.,A4,F10.2,10R4)
      IF(IND) 99,97
   99 RESULT(KTR)= -9E10
      IRESD =IRESD-1
   97 CONTINUE
      IPAGE=IPAGE+1
      IF(KTR.LT.IRES)111,122
  122 WRITE(61,1026)IRES
 1026 FORMAT(//,5X,41HTOTAL NUMBER OF STATIONS IN SORTED LIST =,I6)
      WRITE(61,1027)IRESD
 1027 FORMAT(//,5X,30HNUMBER OF DIFFERENT STATIONS =,I6)
      RETURN
      END
```

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```
      SUBROUTINE SYMINV(A,N,B,MM,DET,IRR)
      DIMENSION A(7260),B(120,1),IP(120)
C     A CONTAINS THE LOWER HALF OF A NXN SYMMETRIC MATRIX STORED COLUMN-
C     WISE,I.E HAS DIMENSION N(N+1)/2
C     B CONTAINS M RHS VECTORS, TO BE REPLACED BY M SOLUTIONS(M MAY=0)
C     IF MM=0,INVERSE ONLY IS GIVEN,MM POSITIVE SOLUTIONS ONLY,MM NEGA-
C     TIVE,BOTH.   M=ABS(MM).
C     THE LOWER HALF OF THE INVERSE MATRIX REPLACES A
C     DET WILL CONTAIN THE DETERMINANT OF A.
      M=IABS(MM)
      DET=1.0
      DO 250 I=1,N
C     CHOOSE LARGEST DIAGONAL ELEMENT AS PIVOT
      AMAX=0.
      II=N*(I-1)-I*(I-3)/2
      K=II
      DO 20   J=I  ,N
      IF(ABS (A(K))-AMAX) 20,20,10
   10 JJ=K
      IP(I) =J
      AMAX=ABS (A(K))
   20 K=K+N-J+1
C     TEST FOR PIVOT TOO SMALL
      IF(AMAX-1.0E-90 ) 30,30,40
   30 IRR=1
      RETURN
   40 DET=DET*A(JJ)
C     SWAP ROWS AND COLUMNS SO THAT A(I,I) IS PIVOT,KEEPING SYMMETRY
      JI=IP(I)-I
      IF(JI)110,110,42
   42 K=II
      KK=K+N-I+JI
      DO 90 L=1,JI
      K=K+1
      AMAX=A(K)
      A(K)=A(KK)
      A(KK)=AMAX
   90 KK=KK+N-I-L
      JJ=I
      K=I
      IF(JJ)55,55,45
   45 DO 50  J=1,JJ
      KK=K+JI
      AMAX=A(K)
      A(K)=A(KK)
      K=K+N-J
   50 A(KK)=AMAX
   55 K=II+JI
      KK=JJ
      JJ=II+N-I
      IF(JJ-K)  80,60,60
   60 DO   70 L=K,JJ
      AMAX=A(L)
      A(L)=A(KK)
      A(KK)=AMAX
   70 KK=KK+1
```

```
   80 IF(M)110,110,100
  100 K=IP(I)
      DO 105 J=1,M
      AMAX=B(I,J)
      B(I,J)=B(K,J)
  105 B(K,J)=AMAX
C     DIVIDE BY PIVOT AND ELIMINATE ONE COLUMN
  110 A(II)=1.0/A(II)
      JJ=I-1
      K=I
      IF(JJ)170,170,115
  115 DO 160 J=1,JJ
      AMAX=A(K)*A(II)
      LL=K-I+J
      LU=K-1
      KK=J-1
      JI=K
      DO 120 L=LL,LU
      KK=KK+1
      A(L)=A(L)+A(JI)*AMAX
  120 JI=JI+N-KK
      A(K)=AMAX
      LL=K+1
      LU=K+N-I
      KK=II
      IF(LU-LL)140,125,125
  125 DO 130 L=LL,LU
      KK=KK+1
  130 A(L)=A(L)-A(KK)*AMAX
  140 IF(M) 160,160,145
  145 DO 150 L=1,M
  150 B(J,L)=B(J,L)+B(I,L)*AMAX
  160 K=K+N-J
  170 JJ=N-I
      KK=II+N-I
      LL=N*(N+1)/2
      IF(JJ) 220,220,175
  175 DO 200 JJ=1,JJ
      J=N+1-JJ
      AMAX=A(KK)*A(II)
      K=KK
      KK=KK-1
      LU=LL+N-J
      DO 180 L=LL,LU
      A(L)=A(L)-A(K)*AMAX
  180 K=K+1
      IF(M) 200,200,190
  190 DO 195 L=1,M
  195 B(J,L)=B(J,L)-B(I,L)*AMAX
  200 LL=LL-N+J-2
      LL=II+1
      LU=II+N-I
      DO 210 L=LL,LU
  210 A(L)=-A(L)*A(II)
  220 IF(M) 250,250,230
  230 DO 240 K=1,M
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  240 B(I,K)=B(I,K)*A(II)
  250 CONTINUE
C     A CONTAINS INVERSE WITH ROWS AND COLUMNS SWAPPED OR
C     B CONTAINS SOLUTIONS WITH ROWS SWAPPED
      IF(M) 280,280,260
  260 DO 270 I=1,N
      L=N-I+1
      K=IP(L)
      DO 270 J=1,M
      AMAX=B(L,J)
      B(L,J)=B(K,J)
  270 B(K,J)=AMAX
      IF(MM) 280,280,370
  280 II=N*(N+1)/2
      DO 360 LL=1,N
      I=N-LL+1
      JI=IP(I)-I
      IF(JI) 360,360,290
  290 K=II
      KK=K+N-I+JI
      DO 350 L=1,JI
      K=K+1
      AMAX=A(K)
      A(K)=A(KK)
      A(KK)=AMAX
  350 KK=KK+N-I-L
      K=I
      JJ=N*(IP(I)-1)-IP(I)*(IP(I)-3)/2
      JJ=I
      IF(JJ) 310,310,295
  295 DO 300 J=1,JJ
      KK=K+JI
      AMAX=A(K)
      A(K)=A(KK)
      K=K+N-J
  300 A(KK)=AMAX
  310 K=II+JI
      KK=JJ
      JJ=II+N-I
      IF (JJ-K) 340,320,320
  320 DO 330 L=K,JJ
      AMAX=A(L)
      A(L)=A(KK)
      A(KK)=AMAX
  330 KK=KK+1
  340 CONTINUE
  360 II=II-N+I-2
  370 IRR=0
      RETURN
      END
```

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```
      SUBROUTINE SORT2(LIST,LENGTH)
C  SORT A LIST OF TYPE INTEGER WORD PAIRS INTO ASCENDING ORDER USING ONLY
C  2 WORDS ADDITIONAL SPACE.
      DIMENSION LIST(2,1)
      N=LENGTH-1
      M=N
      DO 1 I=1,N
      ISWAP=0
      DO 4 K=1,M
      IF(LIST(1,K)-LIST(1,K+1))4,6,3
    6 IF(LIST(2,K)-LIST(2,K+1))4,4,3
    3 LT1=LIST(1,K)
      LT2=LIST(2,K)
      LIST(1,K)=LIST(1,K+1)
      LIST(2,K)=LIST(2,K+1)
      LIST(1,K+1)=LT1
      LIST(2,K+1)=LT2
      ISWAP=ISWAP+1
    4 CONTINUE
      IF(ISWAP.EQ.0)5,1
    1 M=M-1
    5 RETURN
      END
```

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```
      SUBROUTINE SORT22(KEY,DATA,LENGTH)
C     SORT ARRAYS KEY AND DATA USING 2 WORD ELEMENTS OF KEY AS KEY.
      DIMENSION KEY(2,1),DATA(1)
      N=LENGTH-1
      M=N
      DO 1 I=1,N
      ISWAP=0
      DO 4 K =1,M
      IF(KEY(1,K)-KEY(1,K+1))4,6,3
    6 IF(KEY(2,K)-KEY(2,K+1))4,4,3
    3 LT1=KEY(1,K)
      LT2=KEY(2,K)
      KEY(1,K)=KEY(1,K+1)
      KEY(2,K)=KEY(2,K+1)
      KEY(1,K+1)=LT1
      KEY(2,K+1)=LT2
      A=DATA(K)
      DATA(K)=DATA(K+1)
      DATA(K+1)=A
      ISWAP=ISWAP+1
    4 CONTINUE
      IF(ISWAP.EQ.0)5,1
    1 M=M-1
    5 RETURN
      END
```

```
      SUBROUTINE SSEARCH(ITEM,LIST,LENGTH,I)
      DIMENSION ITEM(2),LIST(2,1)
C     SEQUENTIAL SEARCH OF LIST FOR ITEM RETURNING POSITION I OR I-1
C     IF NOT FOUND.
      DO 1 I=1,LENGTH
      IF(ITEM(1).EQ.LIST(1,I))3,1
    3 IF(ITEM(2).EQ.LIST(2,I))2,1
    1 CONTINUE
C     ITEM NOT FOUND
      I=-1
    2 RETURN
      END
```

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1D APPENDIX E 05/11/68

```
      PROGRAM SAFILE
C*****A ROUTINE TO UPDATE LATITUDE AND LONGITUDE DATE, BY STATION
C*****NUMBER
C*****SCRATCH ON LU3, OLD MASTER LU1, NEW MASTER LU2
      REAL LAT,LONG
      INTEGER ENDFLAG,REFLAG
      INTEGER CRDAREA
      INTEGER UPDATE
      INTEGER SAREA,MAREA,AREA,STN,     CSTN,ERROR
      COMMONMAREA(20),SAREA(20),AREA(20),CRDAREA(20,100),JERROR(2,100),
     1IERROR(100),STN(2),CSTN(2),LAT,LONG,EL,GRAV,CLAT,CLONG,ENDFLAG
     2,ERROR(2,100)
      ICOUNT=JJ=J=1
       REFLAG=UPDATE=0
      CALL PREPARE(J1)
   14 READ(1,1)MAREA
    1 FORMAT(20R4)
       IF(MAREA(1).EQ.4RENDS.AND.MAREA(2).EQ.4RAF    )2,3
  700 FORMAT(1X,20R4)
C*****IS AREA IN TABLE
    3 DO 5 I1=1,20
       IF(MAREA(I1).EQ.CRDAREA(I1,I))80,6
    6 GO TO 4
   80 I9=I
    5 CONTINUE
      GO TO 7
    4 CONTINUE
      WRITE(2,1)MAREA
C*****COPY AREA IF NOT IN TABLE
   13 READ(1,9)STN,LAT,LONG,EL,GRAV
    9 FORMAT(R4,1X,R4,2F10.2,2F8.2)
      IF(EOF,1)10,11
   11 WRITE(2,12)STN,LAT,LONG,EL,GRAV
   12 FORMAT(R4,1H.R4,2F10.2,2F8.2)
      GO TO 13
   10 ENDFILE 2
       WRITE(61,88)MAREA
   88 FORMAT(1X,20R4,1X,6HCOPIED    )
      GO TO 14
    7 DO 15 I1=1,20
      CRDAREA(I1,I9)=4R
   15 CONTINUE
C*****AREA FOUND -RUB OUT ENTRY
      REFLAG=0
      GO TO 100
   19 READ(3,200)
  200 FORMAT(1X)
      IF(EOF,3)100,19
  100 READ(3,1)SAREA
      WRITE(61,700)SAREA,MAREA
      IF(SAREA(1).EQ.4RENDS.AND.SAREA(2).EQ.4RAF   )16,17
   17 DO 18 I=1,3
      IF(SAREA(I).EQ.MAREA(I))18,19
   18 CONTINUE
      GO TO 20
   16 IF(REFLAG)21,21,22
```

```
   21 REFLAG=1
      REWIND 3
C*****REWIND AND CONTINUE SEARCH
      GO TO 100
   22 CONTINUE
      WRITE (61,23) MAREA
   23 FORMAT(6HAREA  ,20R4,1X,10HNOT FOUND    )
      REFLAG=0
      GO TO 14
   20 ENDFLAG=0
C*****AREA FOUND
      WRITE(2,1)MAREA
   86 UPDATE=0
   36 READ(3,46)CSTN,CLAT,CLONG
      IF(IOCHECK,3)73,74
   74 IF(EOF,3)24,25
   73 GO TO 36
   24 ENDFLAG=1
   25 READ(1,9) STN,LAT,LONG,EL,GRAV
      IF(IOCHECK,1)71,72
   72 IF(EOF,1)26,27
   71 GO TO 25
   27 IF(ENDFLAG)28,28,31
   28 IF(STN(1)-CSTN(1))31,900,931
  900 IF(STN(2)-CSTN(2))31,30,931
  931 READ(3,46)CSTN,CLAT,CLONG
      IF(EOF,3)24,27
   39 FORMAT(1X,19HNO ELEV-GRAV DATA         ,/,1X,5HAREA ,20R4,/,1X,
     1(4(R4,1H.,R4,2X)))
   42 FORMAT(1X,16HNO LAT LONG DATA     ,/,1X,5HAREA ,20R4,1X,
     1(4(R4,1H.,R4,2X)))
   30 STN(1)=CSTN(1)
      STN(2)=CSTN(2)
      LAT=CLAT
      LONG=CLONG
      UPDATE=1
C*****RECORD UPDATED
   31 IF(GRAV+999.99)33,33,500
  500 IF(EL+999.99)33,33,32
   32 IF(LAT+99999.99)35,35,34
   34 WRITE(2,12)STN,LAT,LONG,EL,GRAV
      WRITE(61,909)CSTN,STN,LAT,LONG,EL,GRAV
  909 FORMAT(1X,2R4,1X,2R4,2F10.2,2F8.2)
   37 IF(UPDATE)86,25,86
C*****ERROR ENTRY
   33 ERROR(1,ICOUNT)=STN(1)
      ERROR(2,ICOUNT)=STN(2)
      ICOUNT=ICOUNT+1
      IF(ICOUNT-101)37,38,38
   38 II=ICOUNT-1
      ICOUNT=1
      GO TO 37
   35 JERROR(1,JJ)=STN(1)
      JERROR(2,JJ)=STN(2)
      JJ=JJ+1
      IF(JJ-101)34,41,41
```

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```
   41 CONTINUE
      JJ=1
      GO TO 34
C*****COMPLETE AREA READ FROM OLD MASTER
   26 IF(ENDFLAG)43,43,44
   43 WRITE(61,45)MAREA
   45 FORMAT(1X,5HAREA ,1X,20HNON UPDATED STATIONS)
   87 CONTINUE
      READ(3,46)CSTN,CLAT,CLONG
   46 FORMAT(2R4,2F10.2)
      IF(EOF,3)44,48
   48 WRITE(61,49)CSTN,CLAT,CLONG
   49 FORMAT(1X,R4,1H,,R4,2X,F10.2.2X,F10.2)
       GO TO 87
   44 JJ=JJ-1
      WRITE(61,88)MAREA
      ICOUNT=ICOUNT-1
      IF(ICOUNT)50,50,51
   51 WRITE(61,39)MAREA,((ERROR(I,J),I=1,2),J=1,ICOUNT)
   50 ICOUNT=1
      IF(JJ)52,52,53
C*****LIST ERROR RECORDS
   53 WRITE(61,42)MAREA,((JERROR(I,J),I=1,2),J=1,JJ)
   52 JJ=1
      ENDFILE 2
      GO TO 14
C*****GO READ NEXT AREA
C*****LIST ANY AREAS IN TABLE NOT UPDATED
    2 DO 56 I=1,J1
      DO 57 II=1,20
      IF(CRDAREA(II,I).EQ.4R     )57,58
   58 GO TO 59
   57 CONTINUE
   56 CONTINUE
      WRITE(2,321)
  321 FORMAT(8HENDSAF      ,72X)
      ENDFILE2
      REWIND 2
   61 STOP
   59 WRITE(61,60)(CRDAREA(I,J1),I=1,3)
   60 FORMAT(1X,5HAREA   ,3R4.13HNOT ON MASTER       )
      GO TO 56
      END
```

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```
      SUBROUTINE PREPARE(J)
C*****INPUT ROUTINE FOR LAT-LONG AREA UPDETE FILE
      COMMON ICFILE(20),IK(20),MFILE(20),CRDAREA(20,100),STN(2,1000),
     1LAT(1000),LONG(1000)
      INTEGER STN,CRDAREA,ICFILE,MFILE,GAR,BAGE
      REAL LAT,LONG
      REWIND 3
      IFLIGHT=0
      J=JJ=1
C***** COMPARE FILE NAMES
      READ(1,1)MFILE
      READ(60,1)ICFILE
    1 FORMAT(20R4)
      DO 40 I=1,20
      IF(MFILE(I).EQ.ICFILE(I))40,2
    2 WRITE(61,4)ICFILE,MFILE
    4 FORMAT(1X,10HCARD FILE ,20R4,/,1X,14HMAG TAPE FILE ,20R4,/,1X,12HJ
     10B DELETED )
    6  STOP
   40  CONTINUE
      WRITE(2,1)MFILE
C*****GET CARD AREA
   21 READ(60,1)(CRDAREA(I,J),I=1,20)
      IF(EOF,60)6,50
   50 IF(CRDAREA(1,J).EQ.4RENDS.AND.CRDAREA(2,J).EQ.4RAF    )8,7
    7  IF(CRDAREA(1,J).EQ.4RENDL.AND.CRDAREA(2,J).EQ.4RATS  )11,9
    9  READ(60,12)
   12 FORMAT(1X)
C***** SKIP FLIGHT CARD
      WRITE(3,13)(CRDAREA(I,J),I=1,20)
   13 FORMAT(20R4)
C***** RAW DATA
   17  READ(60,14)STN(1,JJ),STN(2,JJ),ABLE,BAKER,CHARLIE,DOG,GAR,BAGE
   14 FORMAT(2A4,13X,F2.0,F3.1,F3.0,F3.1,40X,2R4)
      IF(GAR.EQ.4RENDF.AND.BAGE.EQ.4RLGHT)       15,16
C*****SKIP FLIGHT CARD
   15  READ(60,1)GAR,BAGE
      IFLIGHT=IFLIGHT+1
      IF(GAR.EQ.4RENDL.AND.BAGE.EQ.4RATS   )11,17
C*****CONVERT LATS-LONGS
   16 LAT(JJ)=ABLE*60+BAKER
      LONG(JJ)=CHARLIE*60+DOG
      JJ=JJ+1
C***** SENSE TOO MANY STATIONS
      IF(JJ-1000)17,18,18
   18  WRITE(61,20)STN(1,JJ-1),STN(2,JJ-1)
   20 FORMAT(1X,22HSTATIONS EXCEEDS 1000 ,A4,1H.,A4)
C*****IF TOO MANY STATIONS REJECR REMAINDER
   22  READ(60,1)GAR,BAGE
      IF(GAR.EQ.4RENDL.AND.BAGE.EQ.4RATS )11,22
   11  JJ=JJ-1
      CALLORDER(JJ)
C*****SORT AREA
      DO 26 I=1,JJ
C*****AREA RECORDS ON SCRATCH
      WRITE(3,25)STN(1,I),STN(2,I),LAT(I),LONG(I)
```

```
   25 FORMAT(2A4,2F10.2,52X)
   26  CONTINUE
      WRITE(61,30)(CRDAREA(I,J),I=1,20),IFLIGHT,JJ
   30 FORMAT(1X,5HAREA ,20R4,7H COPIED.10X,I3,8H FLIGHTS,10X,I4,8H RECOR
     1DS)
      IFLIGHT=0
      JJ=1
C***** GET NEXT AREA
      J=J+1
      ENDFILE 3
      GO TO 21
    6  WRITE(3,27)
C*****CARD ENDFILE FOUND
   27  FORMAT(8HENDSAF  ,72X)
      ENDFILE 3
      REWIND 3
      J=J-1
      WRITE(61,29)
   29  FORMAT(1X,15HINPUT COMPLETE    )
      RETURN
      END
```

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```
      SUBROUTINE ORDER(K)
      COMMON IDUM1(20),IDUM2(20),IDUM3(20),ICRD(20,100),STN(2,1000),
     1 LAT(1000),LONG(1000)
      INTEGER STN
      REAL LAT,LONG
      DO 1 I=1,K
      L=I+1
      DO2J=L,K
      IF(STN(1,J)-STN(1,I))5,3,2
    3 IF(STN(2,J)-STN(2,I))5,2,2
    5 ITAB1=STN(1,J)
      ITAB2=STN(2,J)
      TAB3=LAT(J)
      TAB4=LONG(J)
      STN(1,J)=STN(1,I)
      STN(2,J)=STN(2,I)
      LAT(J)=LAT(I)
      LONG(J)=LONG(I)
      STN(1,I)=ITAB1
      STN(2,I)=ITAB2
      LAT(I)=TAB3
      LONG(I)=TAB4
    2 CONTINUE
      IF(I-1)9,1,9
    9 IF(STN(1,I)-STN(1,I-1))1,7,1
    7 IF(STN(2,I)-STN(2,I-1))1,8,1
    8 LAT(I)=-99999.99
      LONG(I)=-99999.99
    1 CONTINUE
      RETURN
      END
```

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APPENDIX F

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```
      PROGRAM BA2
      INTEGER ERRORS,PAGE,LCOUNT,IENDSAF,BFLAG,NDCR
      REAL STN1,STN2,LAT,LONG,EL,OGRAV,DCR
      INTEGER HCR,HMT
      INTEGER ACR,AMT
      COMMON HCR(20),HMT(20)
      COMMON ACR(20),AMT(20)
      COMMON ERRORS,PAGE,LCOUNT,IENDSAF(20),BFLAG
      COMMON STN1,STN2,LAT,LONG,EL,OGRAV,LOC1,LOC2
      COMMON DCR(5),DCRB(5),NDCR
      REAL FA,FAB
      REAL DCRB
      REAL BA,BAB
      DIMENSION BA(5),BAB(5)
      REAL BLANK
      INTEGER IBLANK
      DIMENSION IBLANK(2)
      EQUIVALENCE(BLANK,IBLANK)
      COMMON BLANK
      DATA(DUMP=6HDUMP,,)
      REWIND 40
      IENDSAF(1)=4HENDS
      IENDSAF(2)=4HAF
      DO 18 I=3,20
   18 IENDSAF(I)=4H
   30 ERRORS=0
      LCOUNT=0
      PAGE=0
      IBLANK(1)=4H
      IBLANK(2)=4H
C**** CHECK MAG TAPE LABEL=CARD LABEL
      READ(60,41)HCR
   41 FORMAT(20A4)
   50 READ(40,41)HMT
      DO 62 I=1,20
      IF(HCR(I)-HMT(I))70,62,70
   62 CONTINUE
      GO TO 90
   70 PAGE=PAGE+1
      WRITE(61,71)PAGE,HMT,HCR
   71 FORMAT(1H1,6H PAGE ,I3
     1/1X,36H HEADERS ON MT AND CR ARE DIFFERENT
     2/1X,14H MT HEADER IS                              ,20A4,
     3/1X,14H CR HEADER IS ,20A4 )
      STOP
C**** READ AREA AND DENSITY CARDS
   90 READ(60,91)ACR,DCR
   91 FORMAT(20A4,/,5F5,2)
      IF(EOF,60)100,200
C**** END OF DATA ROUTINE
  100 PAGE=PAGE+1
      WRITE(61,101)PAGE,HCR,ACR
  101 FORMAT(1H1,////,6H PAGE ,I3,10X,20A4,/1X,20A4/)
      WRITE(61,111)ERRORS
  111 FORMAT(1X,26H NUMBER OF ERRORS FOUND =  ,I3)
      WRITE(61,121)
```

```
  121 FORMAT(1X,////,11H END OF JOB
      WRITE(59,121)
      REWIND 40
      RETURN
C**** ENCODE BLANKS INTO DENSITY ARRAY
  200 DO 204 I=1,5
      IF(DCR(I)-0.0)202,205,202
  202 ENCODE(8,203,DCRB(I))DCR(I)
  203 FORMAT(F8.2)
  204 NDCR=I
      GO TO 208
  205 DO 207 J=I,5
      ENCODE(8,206,DCRB(J))
  206 FORMAT(8X)
  207 CONTINUE
  208 PAGE=PAGE+1
      WRITE(61,209)PAGE,HCR,ACR,DCRB
  209 FORMAT(1H1,////,6H PAGE ,I3,10X,20A4,/1X,20A4/2X,
     162HSTATION   LOCATION                      LATITUDE   LONGITUDE ELEVATION
     221H    GRAVITY  FREE AIR,5X,31HDENSITIES AND BOUGUER ANOMALIES
     310H (MGAL)   /32X,43H(DEG  MIN)  (DEG  MIN)     (FEET)      (MGAL)
     410H    (MGAL),5(2X,R8))
      LCOUNT=8
C*****SEARCH FOR AREA
  210 READ(40,41)AMT
  220 DO 222 I=1,20
      IF(AMT(I)-IENDSAF(I))230,222,230
  222 CONTINUE
      REWIND 40
      GO TO 300
  230 DO 232 I=1,20
      IF(ACR(I)-AMT(I))240,232,240
  232 CONTINUE
      GO TO 250
  240 CALL SKIP(40)
      GO TO 210
  250 READ(40,251)STN1,STN2,LAT,LONG,EL,OGRAV,LOC1,LOC2
  251 FORMAT(A8,A1,2F10.2,2F8.2,2A8)
      IF(EOF,40)90,260
  260 CALL BASUB2
      GO TO 250
C*****SECOND PASS
  300 READ(40,301)HMT
  301 FORMAT(20A4)
C
  310 READ(40,301)AMT
  320 DO 323 I=1,20
      IF(AMT(I)-IENDSAF(I))430,323,430
  323 CONTINUE
      GO TO 330
  430 DO 432 I=1,20
      IF(ACR(I)-AMT(I))440,432,440
  432 CONTINUE
      GO TO 250
  440 CALL SKIP(40)
      GO TO 310
```

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```
*** ERROR ROUTINE
330 WRITE(61,331)ACR
331 FORMAT(1X,1X,16H AREA NOT ON MT
   1/1X,17H AREA FROM CR IS ,20A4)
    CALL QBQERROR(0,DUMP)
    REWIND 40
    GO TO 50
    END
```

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```
      SUBROUTINE BASUB2
      INTEGER ERRORS,PAGE,LCOUNT,IENDSAF,BFLAG,NDCR
      REAL STN1,STN2,LAT,LONG,EL,OGRAV,DCR
      INTEGER HCR,HMT
      INTEGER ACR,AMT
      COMMON HCR(20),HMT(20)
      COMMON ACR(20),AMT(20)
      COMMON ERRORS,PAGE,LCOUNT,IENDSAF(20),BFLAG
      COMMON STN1,STN2,LAT,LONG,EL,OGRAV,LOC1,LOC2
      COMMON DCR(5),DCRB(5),NDCR
      REAL FA,FAB
      REAL DCRB
      REAL BA,BAB
      DIMENSION BA(5),BAB(5)
      REAL BLANK
      INTEGER IBLANK
      DIMENSION IBLANK(2)
      EQUIVALENCE(BLANK,IBLANK)
      COMMON BLANK
      INTEGER IFA,IFB
      INTEGER LATD,LONGD
      REAL LATM,LONGM
      REAL LAT1,LAT2,NGRAV,K
      BFLAG=0
      IFA=0
      IFB=0
      IF(LAT+99999.0)5,1,1
    1 IF(LONG+99999.0)6,2,2
    2 IF(EL+9999.0)7,3,3
    3 IF(OGRAV+9999.0)8,20,20
    5 ERRORS=ERRORS+1
      BFLAG=1
      IFA=1
      GO TO 1
    6 ERRORS=ERRORS+1
      IFB=1
      GO TO 2
    7 ERRORS=ERRORS+1
      BFLAG=1
      GO TO 3
    8 ERRORS=ERRORS+1
      BFLAG=1
      GO TO 20
   20 FAB=BLANK
      DO 22 I=1,5
   22 BAB(I)=BLANK
   30 IF(IFA)35,34,35
   34 LAT=LAT/60.0
   35 IF(IFB)37,36,37
   36 LONG=LONG/60.0
   37 IF(BFLAG.EQ.1)60,40
   40 LAT1=LAT*3.1415926536/180.0
      LAT2=2.0*LAT1
      NGRAV=978049.0*
     1(1.0+0.0052884*SIN(LAT1)*SIN(LAT1)
     2-0.0000059*SIN(LAT2)*SIN(LAT2))
```

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```
      3-978000.0
      K=EL*0.012770
      DGRAV=OGRAV-NGRAV
      FA = DGRAV + EL*0.09406
   50 DO 55 I=1,NDCR
   52 BA(I)=       FA-K*DCR(I)
      ENCODE(8,54,FAB)FA
      ENCODE(8,54,BAB(I))BA(I)
   54 FORMAT(F8.2)
   55 CONTINUE
   60 IF(LCOUNT-60)70,61,61
   61 PAGE=PAGE+1
      WRITE(61,62)PAGE,HCR,ACR,(DCRB(I),I=1,5)
   62 FORMAT(1H1,////,6H PAGE ,I3,10X,20A4,/1X,20A4/2X,
     162HSTATION   LOCATION                      LATITUDE   LONGITUDE ELEVATION
     221H     GRAVITY  FREE AIR,5X,31HDENSITIES AND BOUGUER ANOMALIES
     310H (MGAL)    /32X,43H(DEG  MIN)  (DEG  MIN)     (FEET)       (MGAL)
     410H     (MGAL),5(2X,R8))
      LCOUNT=8
   70 IF(IFA)72,71,72
   71 LATD=IFIX(LAT)
      LATM=(LAT-LATD)*60.0
      LATM=ABSF(LATM)
      GO TO 75
   72 LATD=900000
      LATM=900000000.
      GO TO 75
   75 IF(IFB)77,76,77
   76 LONGD=IFIX(LONG)
      LONGM=(LONG-LONGD)*60.0
      LONGM=ABSF(LONGM)
      GO TO 80
   77 LONGD=900000
      LONGM=900000000.
   80 IF(OGRAV+9000.0)82,81,81
   81 OGRAV=OGRAV+978000.0
   82 WRITE(61,83)
     1SIN1,SIN2,LOC1,LOC2,LATD,LATM,LONGD,LONGM,EL,OGRAV,
     2FAB,(BAB(I),I=1,5)
   83 FORMAT
     1(X,A8,A1,2X,2A8,2X,2(2X,I4,X,F5.2),2X,F8.1,X,F10.2,6(2X,R8))
      LCOUNT=LCOUNT+1
      RETURN
      END
```

APPENDIX G

```
      PROGRAM NAME
      READ(60,1)ICARD
    1 FORMAT(20A4)
      WRITE(1,1)ICARD
      WRITE(1,2)
    2 FORMAT(80HENDSAF
     1                                         )
      REWIND 1
      STOP
      END
```

APPENDIX H 06/02/69

```
      PROGRAM FIXSAF
      DIMENSION ISTAT(2,1000),LAT(1000),LONG(1000),IHT(1000),IGRAV(1000)
     1,IAREACD(20),ISEG(20),ICDSEG(20),ID(1000)
      DIMENSION LOC1(1000),LOC2(1000)
      REAL LAT,LONG,IHT,IGRAV,LOC1,LOC2
      M=0
      ILK=1
      IN=1
      IOUT=2
    1 READ(60,1001)ICONTROL
      M=M+1
 1001 FORMAT(A4)
 1006 FORMAT(20A4)
 1005 FORMAT(A4,X,A4,2F10.2,2F8.2)
 1002 FORMAT(A4,1H.,A4,2F10.2,2F8.2)
 1007 FORMAT(6HENDSAF,74X)
      IF(EOF,60)100,119
  119 IF(M.GT.1)120,4
  120 ILK=1-ILK
      IF(ILK.EQ.0)121,122
  121 IN=2
      IOUT=3
      GO TO 4
  122 IN=3
      IOUT=2
      GO TO 4
  100 STOP
    4 IF(ICONTROL.EQ.4HC/DE)9,10
    9 READ(60,1006)ICDSEG
 3003 READ(IN,1006)IAREACD
      IF(IOCHECK,IN)3003,3004
 3004 DO 3000 I=1,20
      IF(ICDSEG(I).EQ.IAREACD(I))3000,3001
 3000 CONTINUE
      GO TO 3002
 3001 GO TO 61
 3002 WRITE(IOUT,1006)IAREACD
      READ(60,1006)ICDSEG
   17 READ(IN,1006)ISEG
      IF(IOCHECK,IN)17,18
   18 IF(ISEG(1).EQ.4HENDS)20,19
   19 DO 11 I=1,20
      IF(ISEG(I).EQ.ICDSEG(I))11,12
   11 CONTINUE
      GO TO 13
   12 WRITE(IOUT,1006)ISEG
   16 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
      IF(IOCHECK,IN)16,3005
 3005 IF(EOF,IN)14,15
   15 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
      GO TO 16
   14 ENDFILE IOUT
      GO TO 17
   20 WRITE(61,1020)ICDSEG
 1020 FORMAT(34H SEGMENT TO BE DELETED NOT ON TAPE,2X,20A4)
      WRITE(IOUT,1007)
```

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```
   27 REWIND IN
      REWIND IOUT
      GO TO 1
   13 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
      IF(EOF,IN)21,13
   21 READ(IN,1006)ISEG
      IF(ISEG(1).EQ.4HENDS)23,22
   22 WRITE(IOUT,1006)ISEG
   26 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
      IF(EOF,IN)25,24
   25 ENDFILE IOUT
      GO TO 21
   24 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
      GO TO 26
   23 WRITE(IOUT,1007)
      WRITE(61,996)ICDSEG
  996 FORMAT(5X,20A4,8H DELETED)
      GO TO 27
   10 IF(ICONTROL.EQ.4HC/CR.OR.ICONTROL.EQ.4HC/UP)30,29
   29 WRITE(61,1029)ICONTROL
 1029 FORMAT(38H ILLEGAL CONTROL CARD, COLS 1 TO 4 ARE,2X,A4)
   31 READ(60,1001)ICONTROL
      IF(EOF,60)32,33
   33 IF(ICONTROL.EQ.4HC/CR.OR.ICONTROL.EQ.4HC/UP,OR,ICONTROL.EQ.4HC/DE)
     14,31
   32 STOP
C
   30 K=1
   34 READ(60,1034)ISTAT(1,K),ISTAT(2,K),LATDEG,LATMIN,LATSEC,LONGDEG,LONGMI
     3NGMIN,
     1LONGSEC,IHT(K),IGRAV(K),LOC1(K),LOC2(K)
 1034 FORMAT(2A4,2X,3I2,4X,I3,2I2,F6.1,F10.2,15X,2A8)
      LAT(K)=60.*LATDEG+LATMIN+LATSEC/60.
      LONG(K)=60.*LONGDEG+LONGMIN+LONGSEC/60.
      IF(ISTAT(1,K).EQ.4HEND )36,35
   35 K=K+1
      IF(K-1000)34,34,37
   37 WRITE(61,1037)                                                     1910
 1037 FORMAT(61H NUMBER OF STATIONS IN UPDATING OR CREATING FILE EXCEEDS
     11000 )
      GO TO 1
   36 K=K-1
C*****SORT
      L=K-1
      N=L
      DO 40 I=1,L
      ISWAP=0
      DO 41 J=1,N
      IF(ISTAT(1,J)-ISTAT(1,J+1))41,44,43
   44 IF(ISTAT(2,J)-ISTAT(2,J+1))41,45,43
   43 ITEMP1=ISTAT(1,J)
      ITEMP2=ISTAT(2,J)
      ATEMP3=LAT(J)
      ATEMP4=LONG(J)
      ATEMP5=IHT(J)
      ATEMP6=IGRAV(J)
```

```
      ITEMP7=ID(J)
      ATEMP8=LOC1(J)                $                 ATEMP9=LOC2(J)
      ISTAT(1,J)=ISTAT(1,J+1)
      ISTAT(2,J)=ISTAT(2,J+1)
      LAT(J)=LAT(J+1)
      LONG(J)=LONG(J+1)
      IHT(J)=IHT(J+1)
      IGRAV(J)=IGRAV(J+1)
      ID(J)=ID(J+1)
      LOC1(J)=LOC1(J+1)                     $          LOC2(J)=LOC2(J+1)
      ISTAT(1,J+1)=ITEMP1
      ISTAT(2,J+1)=ITEMP2
      LAT(J+1)=ATEMP3
      LONG(J+1)=ATEMP4
      IHT(J+1)=ATEMP5
      IGRAV(J+1)=ATEMP6
       ID(J+1)=ITEMP7
      LOC1(J+1)=ATEMP8              $            LOC2(J+1)=ATEMP9
      ISWAP=ISWAP+1
      GO TO 41
   45 WRITE( 61,1045)ISTAT(1,J),ISTAT(2,J)
 1045 FORMAT(17H STATION NUMBER  ,A4,1H.,A4,23H APPEARS MORE THAN ONCE)
   41 CONTINUE
      IF(ISWAP)40,42                                                   2310
   40 N=N-1
C
   42 IF(ICONTROL.EQ.4HC/CR)46,47
   46 READ(60,1006)ICDSEG
 4666 READ(IN,1006)IAREACD
      DO 4046 I=1,20
      IF(ICDSEG(I).EQ.IAREACD(I))4046,4047
 4046 CONTINUE
      GO TO 4048
 4047 WRITE(61,1061)IAREACD,IN,ICDSEG
      GO TO 32
 4048 READ(60,1006)ICDSEG
      WRITE(IOUT,1006)IAREACD
   52 READ(IN,1006)ISEG
      IF(IOCHECK,IN)52,302
  302 WRITE(IOUT,1006)ISEG
      IF(ISEG(1).EQ.4HENDS)50,53
   53 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
 1053 FORMAT(A4,X,A4,2F10.2,2F8.2,2A8)
      IF(IOCHECK,IN)53,303
  303 IF(EOF,IN)4049,51
   51 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,HT,GRAV,LOC1,LOC2
 1051 FORMAT(A4,1H.,A4,2F10.2,2F8.2,2A8)
      GO TO 53
 4049 ENDFILE IOUT
      GO TO 52
   50 BACKSPACE IOUT
      WRITE(IOUT,1006)ICDSEG
      PRINT 301
  301 FORMAT(6H 11111)
      DO 54 I=1,K
      IF(LAT(I).EQ,0.)55,56
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
   55 BLAT=-99999.00
      GO TO 556
   56 BLAT=LAT(I)
  556 IF(LONG(I).EQ.0.)57,58
   57 BLONG=-99999.00
      GO TO 59
   58 BLONG=LONG(I)
   59 IF(IHT(I).EQ.0.)559,558
  559 HT=-999.00
      GO TO 554
  558 HT=IHT(I)
  554 IF(IGRAV(I).EQ.0.)555,560
  555 GRAV=-999.00
      GO TO 557
  560 GRAV=IGRAV(I)+0.43
  557 WRITE(IOUT,1051)ISTAT(1,I),ISTAT(2,I),BLAT,BLONG,HT,GRAV,LOC1(I),LOC2(
     1OC2(I)
   54 WRITE(61,1059)ISTAT(1,I),ISTAT(2,I),BLAT,BLONG,HT,GRAV,LOC1(I),LOC2(I)
     22(I)
 1059 FORMAT(X,A4,1H.,A4,2F10.2,2F8.2,2X,2A8)
      ENDFILE IOUT
      WRITE(IOUT,1007)
      REWIND IN
      REWIND IOUT
      WRITE(61,1060)ICDSEG,IOUT
 1060 FORMAT(9H SEGMENT ,20A4,20H CREATED ON TAPE LU ,I3)
      GO TO 1
C**** UPDATE
   47 READ(60,1006)ICDSEG
   62 READ(IN,1006)IAREACD
      DO 60 I=1,20
      IF(ICDSEG(I).EQ.IAREACD(I))60,61
   61 WRITE(61,1061)IAREACD,IN,ICDSEG
 1061 FORMAT(X,6HTAPE  ,20A4,14H LOADED ON LU ,I3,/,X,11HSHOULD BE  ,
     120A4)
      GO TO 32
   60  CONTINUE
      WRITE(IOUT,1006)IAREACD
      READ(60,1006)ICDSEG
      IFOUND=0
      WRITE(61,1062)IAREACD,ICDSEG
 1062 FORMAT(1H1,X,32H DATA USED TO UPDATE TAPE NAME  ,/,X,20A4,//,27H F
     1ILE ON TAPE UPDATED NAMED,X,20A4)
   71 READ(IN,1006)ISEG
      WRITE(IOUT,1006)ISEG
      IF(ISEG(1).EQ.4HENDS)63,64
   63 IF(IFOUND-1)66,65
   66 WRITE(61,1066)ICDSEG,IAREACD
 1066 FORMAT(X,50(1H*),5HAREA ,20A4,16HNOT ON SAF FILE ,20A4)
   65 WRITE(61,1065)IOUT
 1065 FORMAT(X,13HLOGICAL UNIT ,I3,3X,21HIS LATEST OUTPUT TAPE)
      REWIND IN
      REWIND IOUT
      GO TO 1
C
   64 DO 67 J=1,20
```

```
      IF(ICDSEG(J).EQ.ISEG(J))67,68
   67 CONTINUE
      IFOUND=1
      GO TO 72
   68 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
      IF(EOF,IN)70,69
   69 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
      GO TO 68
   70 ENDFILE IOUT
      GO TO 71
C
   72 IEND=IR=0
      KTR=0
   73 KTR=KTR+1
       IF(KTR.GT.K)117,74
   74 IF(IEND.EQ.1)83,77
   77 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
      IF(EOF,IN)78,79
   78 IEND=1
       GO TO 83
   79 IF(ISTN1-ISTAT(1,KTR))81,82,83
   82 IF(ISTN2-ISTAT(2,KTR))81,84,83
   84 IF(ID(KTR).EQ.1HD)73,86
   86 IF(LAT(KTR).EQ.0.)87,88
   88 BLAT=LAT(KTR)
      GO TO 91
   87 BLAT=ALAT
   91 IF(LONG(KTR).EQ.0.)89,90
   90 BLONG=LONG(KTR)
      GO TO 92
   89 BLONG=ALONG
   92 IF(IHT(KTR).EQ.0.)94,93
   93 HT=IHT(KTR)
      GO TO 944
   94 HT=ELEV
  944 IF(IGRAV(KTR).EQ.0.)96,95
   95 GRAV=IGRAV(KTR)
      GO TO 97
   96 GRAV=GRAVITY
   97 WRITE(IOUT,1051)ISTN1,ISTN2,BLAT,BLONG,HT,GRAV,LOC1(KTR),LOC2(KTR)
      GO TO 73
C     NO NUMBER IN CORE TO UPDATE NUMBER ON TAPE
   81 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
      GO TO 74
C     NO NUMBER ON TAPE FOR NUMBER IN CORE
   83 IF(LAT(KTR).EQ.0.)101,102
  101 BLAT=-99999.00
      GO TO 103
  102 BLAT=LAT(KTR)
  103 IF(LONG(KTR).EQ.0.)104,105
  104 BLONG=-99999.00
      GO TO 106
  105 BLONG=LONG(KTR)
  106 IF(IHT(KTR).EQ.0.)107,108
  107 HT=-999.00
      GO TO 109
```

```
108 HT=IHT(KTR)
109 IF(IGRAV(KTR).EQ.0.)110,111
110 GRAV=-999.00
    GO TO 112
111 GRAV=IGRAV(KTR)
112 WRITE(IOUT,1051)ISTAT(1,KTR),ISTAT(2,KTR),BLAT,BLONG,HT,GRAV,
   1LOC1(KTR),LOC2(KTR)
    KTR=KTR+1
    IF(KTR.GT.K)113,114
113 IR=1
    IF(IEND.EQ.1)115,116
114 IF(IEND.EQ.1)83,79
117 READ(IN,1053)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
    IF(EOF,IN)115,116
116 WRITE(IOUT,1051)ISTN1,ISTN2,ALAT,ALONG,ELEV,GRAVITY,LOC1,LOC2
    GO TO 117
115 ENDFILE IOUT
    GO TO 71
    END
```